Optimization of Concrete Strength using Local Aggregates from the Eastern Province of Saudi Arabia

by

Muhammad Hamad Al-Rugaib

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

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In Partial Fulfillment of the
Requirements for the Degree of

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THE GRADUATE SCHOOL

This Thesis, written by Mr. Muhammad Hamad Al-Rugaib under the direction of his Thesis Committee, and approved by all its members, has been presented to and accepted by the Dean of the Graduate School, in partial fulfillment of the requirements for the degree of M.S.

Hashim A. Yamani
Dr. Hashim A. Yamani
Dean of the Graduate School

Date 06-08-1978

For Dr. Abdalla I. Sayyari
Department Chairman

Thesis Committee

Nabil Shoeb
Dr. Nabil Shoeb, Chairman

T. G. Brown
Dr. Tom Brown, Member

Dr. Muhammad H. Baluch, Member

This Thesis is dedicated to my parents and my wife for the great support they gave me while conducting this research.

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ABSTRACT

In the Eastern region of Saudi Arabia on the Arabian Gulf, concrete has been typically quite low in strength and of poor quality. This is attributed to a variety of reasons. The coarse aggregates used in that area in making concrete is mainly obtained from crushing limestone and dolomite rocks that vary appreciably in quality and strength from one quarry to another. Many of the aggregates used are very weak in strength and come from friable chalky rocks that have poor soundness and abrasion characteristics. Also, the fine aggregates i.e. sand in the area is typically very fine and mainly monogranular. In addition to the above factors lack of quality control, poor workmanship, no gradation nor washing of the coarse aggregates and no control on the amount of water used in the mix, aggrevate the problem. The 28 days compressive strength of concrete that is usually obtained in the area is 2500 psi, maximum.

In view of the above, an experimental two pronged research program was conducted seeking to obtain the best aggregates available in the area and then to optimize the concrete strength using the selected aggregate and other local materials. Improving the quality and hence the strength of concrete is of paramount importance in this area considering the extreme changes in temperature and humidity that affects the concrete adversely. In addition high strength concrete is required for the prestressed-precast industry

that is developing in the area to alleviate the housing shortage in a rapidly growing country.

Research performed showed a wide range of available aggregates. Their qualities varied from poor to sound and hard aggregates. Incorporation of good quality aggregates, a good mix design, use of admixtures, following the recommended practice for producing high strength concrete led to a remarkable increase in concrete strength. Concrete with 28-days compressive strength of 6000 to 8000 psi was achieved. These strengths were achieved by using conventional concrete materials and practices with emphasis on the following:

1) Selecting good quality aggregates.
2) Washing the aggregates.
3) Finding the optimum maximum size for coarse aggregate.
4) Grading the aggregates within the ASTM C33 limits.
5) Using selective fine aggregates.
6) High cement factor up to 10 sacks per cubic yard.
7) Low water cement ratios (0.35).
8) The use of admixtures to improve workability without requiring additional water.
9) Optimize the fine aggregate to coarse aggregate ratio.
10) Thorough mixing and vibration.

1. INTRODUCTION

1.1 Object and Scope

Concrete is the most widely used building material in the Middle East. The tremendous amount of construction which is going on presently in Saudi Arabia and which will continue for at least a decade to come is utilizing enormous quantities of concrete.

In the Eastern Province of Saudi Arabia the available known fine and coarse aggregates and the local practice of making concrete produce poor quality and low strength concrete. Also, the climatic conditions in the Eastern Zone (The Gulf Area) are severe. The change in temperature from day to night is extreme, and ranges from $120^{o}F$ to $60^{o}F$ in 24 hours. Also the change between winter and summer is very pronounced. Similarly the variation in humidity is severe. These factors severely affect the quality of concrete causing cracking and disintegration.

The coarse aggregates are obtained by crushing limestone and dolomite rocks that are common in the Eastern region. The quality of aggregate varies appreciably from one quarry to another. Many of the aggregates used are very weak in strength, quite friable, chalky and have poor soundness and abrasion properties. One of the major construction firms participating in the Jubail industrial complex project hauled rocks by barges across the Arabian Gulf all the way from Ras El-Khemah in the United Arab Emirates to be crushed and used to produce good quality concrete and for port construction. This of coarse is the result of lack of information whether it is possible to get good quality aggregates from the quarries in the Eastern region or not.

The sand in the Eastern region is typically very fine and mainly single sized. One has to be quite selective in choosing where to get the sand from to achieve coarser particles.

This study has two main objectives. The first is to survey a large number of the quarries in different locations in the Eastern region and to test the qualities of the coarse aggregates produced from these quarries. From these results the best coarse aggregates available is determined. The second objective is to optimize the concrete strength using the selected coarse aggregate, the local sand trying to choose the best available, and local Saudi produced cement. The concrete mix is designed using all local materials and the various factors affecting the strength are studied and optimized.

Achieving high strength and good quality concrete is of extreme importance to the Eastern Zone of Saudi Arabia. The strength of concrete in general is an index for its durability. Recent articles by Fookes, Collis, French and Poole [4] showed many examples of deterioration of concrete construction in many parts of the Middle East. Selecting good aggregate and achieving a good mix design will alleviate this problem. In addition, in the precast industry or in prestressed concrete technology high strength concrete is a must. In order to use very high strength steel strands efficiently high strength concrete is required. Precast techniques are highly needed to expedite the construction of concrete building to solve the housing embarking on an ambitious development plan.

1.2 Literature Review

1.2.1 High Strength Concrete

The search for methods of design and production of high strength concrete is one of the major objectives of most of the organizations that deal with building materials in general, and with concrete in particular.

Concrete Technology Associates [1] (C.T.C) made a study for high strength concrete production based on research conducted at their laboratories. The study was divided in three parts as follows:

a) Application of High Strength Concrete: High strength concrete is mainly used in prestressed concrete members because it improves the structural performance. Longer spans, wider spacing of girders, and thinner sections can be made efficiently with high strength concrete.

b) Behavior and Application of Materials:

Cement: High early strength cement (type III) was used. It is recommended to look for the following characteristics in type III cement:

1) High Fineness: 5,000 - 6,000 blaine.
2) The cement should contain 60 to 70 percent tricalcium silicate C_3S.
3) Low water demand.
4) Final penetration of paste = 50% or more of initial penetration according to standard specification for Portland Cement (ASTM C150).
5) High 28-days compressive strength of mortar cubes 7,000 - 8,000 psi.

Aggregates: Research at C.T.C. showed that there is a considerable increase in the compressive strength when the bond of aggregates to cement paste is improved. Coarse aggregates should be washed to remove fines. Gain in slump can be attained by presoaking of the aggregates. Also the compressive strength of concrete can be increased by reducing the maximum size of aggregates. Test showed that 3/8 and 1/2 - inch aggregates should be used with high cement factors. A coarse natural sand is advantageous for strong dense concrete. Fine aggregates having fine particles passing the No.50 sieve should not exceed the limits of 0-to 10 percent.

Admixtures: Water reducing and retarding admixtures meeting ASTM C494 specification are universally used for their benefits. In rich mixes with low slump, significant increases in concrete strength and workability can be made by using larger than normal dosages of water reducers. Retarding water reducers yield considerable improvement in concrete performance with cements which have low C_3A contents (less than 8%) and low alkalis (less than 0.60 percent).

c) Optimized Mix Design: Concrete materials should be selected after careful analysis of their behavior. A testing program was conducted at C.T.C. with emphasis on the following:

1) Low sand to aggregate ratio of 0.35.
2) Mix with maximum density.
3) Continuous gradation of dry materials.
4) Optimum matrix volume.
5) Trial mix verrification and adjustment

Portland Cement Association published a paper (2) by Sidney Freedman discussing different aspects of the techniques employed in producing high strength concrete. Freedman defines high strength concrete as concrete with a specified compressive strength of at least 6,000 psi at 28-days. Freedman believes that high strength concrete is achieved by optimization of the following factors:

1) Characteristics of cementing medium.
2) Characteristics of the aggregates.
3) Proportions of the paste.
4) Paste-aggregate interaction.
5) Mixing, consolidation, and curing.
6) Testing procedures.

Freedman suggests that Portland cement should be used based on comparative strength tests of concrete tested at 28 and 90 days with cement content ranging from 660 to 940 lb. per cu. yd. Cement which yields higher compressive strength at extended ages is preferable. Tests on different sizes of coarse aggregates showed that 3/8 inch maximum size yield higher strength with high cement content. It is recommended to use aggregates gradation within the limit specified by ASTM C33. Natural gravel aggregates are not recommended if they are weathered. Also aggregates with high absorption are not suitable. Fine aggregates which are smooth and rounded with fineness modulus of 2.7 to 3.2 are preferable. The study recommends washing the sand if it contains large quantities of mica, certain clay minerals, or other deleterious materials. Water-reducing retarders which meet the requirements of ASTM C494 should be considered because their use generally leads to a higher concrete strength.

Freedman further stresses the importance of the trial mix approach of selecting proportions for high strength concrete optimization rather than any theoretical approach.

Ronald L. Blick (3) published a paper in Modern Concrete summarizing some of the factors influencing high-strength concrete. In his study Blick showed that the type of cement used makes a difference in the strength. He recommends a periodical testing of the quality of the cement. The optimum cement content can be established by several trial mixtures using a single set of aggregates and fixed slump. Blick points out that the ACI proportioning should be modified because of the extremely high percentage of cementitious materials used in high strength concrete. Also, he suggests using a very low water-cement ratio, but only after optimizing the other materials. It is recommended that admixtures with different dosages be used so as to see the gain in strength. Also the use of 10% to 15% fly ash (by weight of cement) is recommended. Tests showed that crushed aggregates yield a higher strength than natural gravel. Mixes using coarse aggregates with maximum size of 3/8 in and graded according to the ASTM C33 limits yielded superior results. The fine aggregates, with a fineness modulus around 3.0, which are considered coarse under normal conditions, provided the best workability and highest compressive strength.

In the recently published book Concrete in the Middle East (4) there are five articles previously published by the Cement and Concrete Association. The emphasis in all of these five articles is on the materials behavior and the geology of the area. The five articles elaborate on the detrimental effects of the alkali aggregate reactions.

However, the authors complain that detailed information is not available and they recommend much more intensive field work. In the article "Aggregates and the Middle East" (5) there are excellent guidelines for detailed evaluation of potential aggregates sources in the Middle East.

2. GEOMORPHOLOGY OF THE EASTERN PROVINCE

2.1 Geological Formations

In the Eastern Province there are some places where outcrops of rocks suitable for concrete are to be found. These rocks are used by the crushing plants to make coarse aggregates for concrete. The main rock formation that is used as a source of aggregates is limestone. The geological formations of the Eastern Province (6) where these deposits exist are described below and a map showing the various locations is shown in Figure (1):

2.1.1 Rus Formation

Named after Umm al-Ru'us which is a small hill located at latitude 26° 19' N. and longitude 50° 08' E. near Dhahran. The Rus formation consists of several layers. These layers starting from the top are:

a) White soft chalky porous limestone, 3.6 m thick.

b) Light colored marl and some limestone beds with a total thickness of 31.8 m.

c) Gray limestone with a total thickness of 21 m.

This formation is found in two areas:

i) 180 km North of Wadi Sahba; see map Figure (1)

ii) An area with a radius of 5 km with Jabal Umm al-Rus as a center which is near Dhahran city.

2.1.2 Dammam Formation

The Dammam formation is named after the Dammam Dome and is located at latitude 26° 19' 16" N. and longitude 50° 04' 50" E. The Dammam formation is fully exposed and it takes the shape of an oval escarpment around the Dammam Dome with an average inside diameter of 10 km and an average outside diameter of 18 km. It has a maximum thickness of 32.5 m. The Dammam formation can be divided in to five members as follows:

a) Alat member: Named after Al Alat well, located at latitude 26° 27' 49" N. and longitude 49° 50' 11" E; it consists of a large amount of limestone (9 m thick) and a layer of marl (6 m thick).

b) Khobar member: Named after Al-Khobar town; it consists of Khobar dolomitic limestone and Khobar marl.

c) Alveoline limestone member: It consists of limestone that is 1 m thick.

d) Saila Shale member: Brownish-yellow clay shale 3.6 m thick and 0.6 m thick gray limestone.

e) Midra Shale member: It consists of an exposed yellow-brown shale 3 m thick.

2.1.3 Hadrukh, Dam, and Hofuf Formations

These formations are in the interior away from the coast. They contain marine fossils in a sedimentary fashion which indicates that at one time that area was covered by sea. It can be divided into three distinctive formations as follows:

a) Hadrukh Formation: Named after Jabal al Hadrukh and is located at latitude 27° 04' 36" N. and longitude 49° 11' 24" E. This formation consists mainly of cream colored sandy clay sandstone, and non-sandy limestone.

b) Hofuf Formation: Named after Hofuf town and is located at latitude 25° 22' N. and longitude 49° 35' E. One of the main features of the Hofuf formation is the Shedgum Plateau. This formation consists of 9.1 m thick marly conglomerate limestone boulders, red and white sandstone, and white limestone.

2.2 Surface Features

In addition to the geological formation mentioned above which describe the different geological sections existing in the Eastern Province, there are some surface features which should be considered so as to give a comprehensive view of the geological forms of the Eastern Province. These features are as follows:

2.2.1 Sand

Sand covers almost all the Eastern Province except the limited areas where rock formations or Sabkhah deposits are on the ground surface. In addition to the above there is a massive body of sand to the South of the Eastern Province called Al-Rub'al Khali. Also, there is another body of sand to the West of the Eastern Province called Dahna.

Sand is divided into four classes as follows:

a) Transverse: Simple sand dunes of mobile sand located transverse to the wind direction.

b) Longitudinal: Which is bush or grass-covered sand parallel to wind direction.

c) Urug: Which are long nearly parallel, sharp-crested narrow sand ridges and dune chains usually separated by the broad valleys, and they are usually developed by two dominant wind directions.

d) Sand mountains: A massive sand cresting up to 300 m above substratum, some as a result of superposition of many sand dunes.

2.2.2 Gravel

Gravel in the Eastern Province is located in scattered isolated patches. The gravel is generally made up of well-rounded white quartz pebbles as large as 10 cm in dimeter. This gravel is to be found in the following locations:

a) In and near Wadi Sahba between latitude 24^{O} and longitude 48^{O} 35' E., see Figure (2). Here the quantity of gravel increases from West to East representing an old major drainage channel.

b) In Ad-Dhahna 40 km South of Wadi Sahba.

c) In the bottom of Wadi Al-Batin.

d) Sheet gravel found in the Ad-Dibdibah plain in the Northern Section of the Eastern Province.

The possibility of using the natural gravel from these places is not economical at the present time because there are no paved roads reaching these places, and because some of the areas where gravel is available are restricted for public use and are considered military grounds.

2.2.3 Sabkhah Deposits

Sabkhah is an Arabic term for coastal and inland saline flats built up by the deposition of silt clay and muddy sand. In some areas where salt is mined Sabkhah is then called Mamlahah. Sabkhahs are located in a narrow belt along the coast from Kuwait to the East of Qatar within 60 km of the shoreline. An example of such Sabkhah deposit is the one the traveller to Jubail can see on both sides of the road.

3. AGGREGATE QUARRIES STUDY

3.1 General

A great expansion in concrete construction is going on in the Eastern Province and it is expected to continue for at least twenty years to come. Since coarse aggregates make up at least 40% of the total volume of concrete, its selection and proportioning should be given careful attention in order to control the concrete quality. Most of the coarse aggregates used in concrete construction in the Eastern Province come from limestone and dolomite deposits. These deposits when found, may be of a friable and porous nature and also be contaminated with deleterious salts. The state of contamination by salts and the poor nature of many rocks is such that carefully selective quarrying may be essential to get a satisfactory end product.

Arabian American Oil Company (ARAMCO)[7] and the Saudi Industrial Development Fund (SIDF)[8] both have made studies about the existing crushed rock industry in the Eastern Province. Aramco's study showed that the annual estimated production of crushed aggregates is 8.3 million cubic yard in 1977 in one work shift. The demand for crushed rock at that year was 16 million cubic yard. This shortage was alleviated by operating some of the plants at 2 shifts a day while some others were operating continuously. The S.I.D.F. interviewed most of the quarries in the Eastern Province. In the S.I.D.F study a general information about each quarry was reduced in tabular form. The information collected includes production rate, price, sizes produced and qualification of the aggregates. The qualification was based on field inspection and not on any test data.

The strength of concrete up to about 8000 psi depends essentially on the quality of the hardened cement paste that holds the aggregate particles together. The aggregate at this strength level nearly always has much greater strength than the cement paste. In highstrength concrete the quality and the strength of the aggregates should be carefully inspected.

In view of the preceding discussion a survey of the major quarries in the Eastern Province was essential to assess the quality of aggregates available and to choose the best quarry for concrete strength optimization.

3.2 Quarries Selection

Coarse aggregate quarries are scattered over a wide area in the Eastern Province but are mainly in the neighbourhood of the residential areas, Dhahran, Khobar, Hofuf, and Safania. Most of the quarries in each of the four areas were taken for preliminary study and the location of each one was determined. Twelve quarries were selected for conducting this research and the selection was based on the following guidelines:

a) geological study of the area

b) size of the quarry

c) locations

d) ministry of petroleum and mineral resources licensed quarries (Appendix A).

e) purpose of the quarry usage.

f) production availability.

After these twelve quarries were chosen a questionnaire data sheet was distributed to each quarry (Appendix B). The majority of the owners of the crushed rock plants were mainly concerned about getting the license for production without taking any actual scientific steps in choosing the quarry location. Few quarries give some consideration to the gradation of the aggregates. Generally most of the aggregate sizes are produced in all quarries but the people responsible at the plant have little knowledge about the application of the different aggregate sizes. The average production rate is 700 cubic yards per day per quarry. More than 50% of the quarry managers complain about the low market. This led to a remarkable reduction in the price of about 60%. It is expected with surplus of the material available more attention will be given to the quality. A map in Figure (2) shows the exact location of each of the twelve quarries.

3.3 Production and Prices

Crushed rock plants are divided (7) into three categories as follows:

1) Plants producing for internal use

2) Plants producing for selling

3) Plants producing for internal use but selling the surplus.

In most of the quarries, the bedrock is blasted periodically, the huge pieces are rejected and the pieces which are within the capacity of the plant are loaded into lorries and taken to the crusher plant. Few plants are shoveling the rocks from the ground surface to within a depth of one meter. Crusher plants produce a wide range of sizes suitable for both building and highway construction.

From Figure (3) the actual capacity of the crusher plants is 8.3 million cubic yard of crushed aggregates per year. This figure is based on a regular one-shift basis. The theoretical capacity of these plants is much higher, and it could be 33 million cubic yards annually if they were producing at a rate of three 8-hour shifts/day. This explains how the gap in Figure (3) between the capacity and demand is solved. Several plants operated by foreign companies have recently started production. The output of these plants, however, was not taken into account in estimating the total capacity.

In recent years prices of crushed aggregates have fluctuated a great deal due to the unstability in supply and demand. At the beginning of 1976 selling price went up to 110 SR per cubic yard because there was a severe shortage of the product. At that time several contractors imported natural aggregates from Riyadh area at a lower price. Prices started to go down with the increase in production. The Saudi Government regulated the price at 50 SR per cubic yard by the end of 1976. At the end of 1977 prices started to go below the government regulated prices. This drop in prices should not be construed as due to a drop in demand but it came as a result of fact that numerous major construction companies use their own crushers. This practice adversely affected those plants which produce aggregates for general sale.

3.4 Sampling Procedure

There are several methods that can be employed to get a sample from the plant. The procedure in sampling aggregates (ASTM Standard D 75) recommends different methods. The method used in this study is taking the sample from stockpiles. About 150 lb. was collected from each crusher plant. The amount is much higher than the specified minimum, so that there would be enough quantity for all the tests. The sample was collected from different portions of the stockpiles, so that there would be no segregation in the sample. Thick clean sacks were used to collect the sample.

The field sample was reduced to the appropriate size for testing by using the riffle sample splitter according to ASTM C 702 which is equipped with two receptacles to hold the sample. This method involves continuous reduction until the size specified for the intended test is reached. The portion of the material collected in the other receptacle was reserved for reduction in size for other tests.

3.5 Aggregate Testing

3.5.1 General

There are two main series of tests conducted on coarse aggregate. The purpose of the first series of tests is to get some knowledge about the quality of the different available aggregates so that it is possible to choose the best for the concrete strength optimization. The tests that had been done according to the Standard Specifications for concrete aggregates (ASTM C 33) are as follows:

a) Test for resistance to abrasion of small size coarse aggregates by use of Los Angeles Machine, ASTM C 131.

b) Test for soundness of aggregates by use of sodium sulfate or magnesium sulfate, ASTM C 88.

c) Test for clay lumps and friable particles in aggregates, ASTM C 142.

d) Petrographic examination of aggregates for concrete, ASTM C 295.

e) Test for compressive strength of coarse aggregates cubes.

Additional tests were conducted to determine the amount of contaminated soluble salts, the PH value, hardness, and total alkalinity.

A second series of tests on coarse aggregates were conducted to get the information needed for the calculation of batch quantities, for making mix adjustments, for computing effective water-cement ratios, and for making estimates for quantities required for the concrete mixes. These tests are as follows:

a) Sieve analysis of fine and coarse aggregates, ASTM C 136.

b) Unit weight of aggregate, ASTM C 29.

c) Specific gravity and absorption of coarse aggregates, ASTM C 127.

d) Specific gravity and absorption of fine aggregates, ASTM C 128.

It was decided to run tests a and b in the first series and all the second series tests on the samples from all twelve quarries. Based on the results obtained in the abrasion tests, the soundness tests, the absorption tests and the unit weight tests the three best quality aggregates were chosen amongst the twelve quarries. The intent was to use these three different aggregates in the concrete mixes to get the highest possible strength as will be explained later in Chapter 4. The test for clay lumps was limited for the three best aggregate samples. The petrographic test was actually limited to one sample only that had the best results overall to get an idea about the mineral composition of the rocks used in that crusher. Similarly the contaminated soluble salts and the compressive strength of the rock sample was also limited to the chosen best one.

3.5.2 Sieve Analysis of Fine and Coarse Aggregates, ASTM C136

The objective of this test is to know the grading for each of the samples collected from the twelve quarries to determine whether it meets the ASTM C 33 requirements or not. A minimum test sample of 12 kg is used from each quarry. The data from sieve tests are recorded and reduced in tabular form in Tables (1) to (13) corresponding to each quarry. The maximum size of each sample is determined from its sieve analysis and is generally designated by the commercial sieve size next coarser than the largest size on which 15 percent or more is retained. It was decided to get from the crushers what is sold as 3/4 of an inch aggregate for all the aggregate testing since this is the most commonly used size in concrete construction.

The results of the sieve analysis on the samples obtained showed that the maximum size of the aggregates used in all the quarries was not always 3/4 of an inch, but sometime it was 1-inch. A grading chart for each quarry sample is drawn. This is illustrated in Figure (5) to Figure (16). From the sieve analysis tables and the grading charts, one concludes that most of these samples are almost single sized and poorly graded. Generally for the 3/4 inch maximum size samples the percent passing 3/8 inch sieve is about 3%. This is much lower than the recommended values by ASTM C 33 that ranges between 20 to 55%. Samples taken from quarry No.1 does meet the grading limits of ASTM, as seen in Figure (5). Similarly the same results are obtained for the 1 inch maximum size sample showing also poor grading. In general it is found from the gradation tables and charts that the coarse aggregates in all twelve quarries tend to contain larger percentage of the coarser particles than the finer ones. In Figure (17) the gradation limits as recommended by ASTM C 33 for 3/4 inch maximum size is shown for comparison with the gradation obtained for the different above mentioned samples.

Fine aggregates sieve analysis is shown in table (13), and the gradation curve is shown in Figure (20). Figure (21) shows the fine aggregates gradation limits specified by ASTM C 33. Comparing the two figures it is clear that the gradation of the fine aggregates used falls within the ASTM limits for all sieves except sieve No. 16. The critical deficiency in the fine aggregates is that the percent passing sieve No. 16 is 98.78% instead of the ASTM specified limits which are 50% to 85%. It is also noticed that the percentages passing sieves No. 4 and No. 8 (with the larger opening) are very close to the upper limit specified by ASTM specifications, while the percentages passing sieves No. 30, 50 and 100 (with smaller openings) tend to be close to the lower limit specified by ASTM C 33. The fineness modulus of the fine aggregates was calculated from the sieve analysis table (13) to be 2.7. It represents the (weighted) average sieve of the group upon which the material is retained, No.100 being the first, No. 50 the second, etc.

3.5.3 Unit Weight of Coarse Aggregates, ASTM C 29

The unit weight of the coarse aggregates is determined by weighing the aggregates required to fill in an appropriate container of known volume as recommended by ASTM C 29 and is usually measured in pounds per cubic foot. The unit weight is determined for the purpose of mix proportion estimation, mainly to convert quantities by weight to quantities by volume. The compacted dry unit weight of each of the twelve quarries test samples is shown in table (14) to table (25). These value range between 81 to 92 pounds per cubic foot. The general range of unit weight of common crushed stone[9] is 95 to 103 pounds per cubic foot which shows that the available aggregate is about 10% lower than the common. The compacted dry unit weight is also necessary for comparing different aggregates sources. Generally the greater the unit weight, the smaller the percentage of voids and that yields better gradation of the particles. Since the percentage of solids and the percentage of voids are controlled to a considerable extent by the grading, shape, and surface texture of the particles, the unit weight and void content then serve as a rough index of the efficiency of the grading. The unit weight is also affected by the specific gravity, the moisture condition of the aggregate, and the compactness of the mass.

3.5.4 Specific Gravity and Absorption, ASTM C 127

The specific gravity is the ratio of the unit weight of the material to the unit weight of water. It is calculated according to the ASTM C 127 specification. In concrete aggregates, the expression specific gravity refers to the density of the individual particles, not the aggregated mass as a whole. The apparent specific gravity is the ratio of the weight of the aggregate dried in an oven at 100 to 110^{o}C (212 to 203^{o}F) for 24 hours to the weight of water occupying a volume equal to that of the solid including the impermeable pores. Limestones apparent specific gravity [10] range between 2.5 to 2.8 with an average of 2.66. The twelve quarries test samples yielded an apparent specific gravity in the range of 2.63 to 2.82. The apparent specific gravity of aggregates depends on the specific gravity of the minerals of which the aggregates is composed of and also on the amounts of voids. Concrete mix proportion calculation is generally based on the bulk specific gravity (saturated surface-dry condition) of the aggregate because the water contained in all the pores in the aggregate does not take part in the chemical reactions of cement and can, therefore, be considered as a part of the aggregate. The bulk specific gravity is defined as the ratio of the weight in air of a given volume of a material (including both the permeable and impermeable voids normal to the material) at the standard temperature to the weight in air of an equal volume of distilled water. Limestone [9] has a bulk specific gravity satu-rated surface-dry in the range of 2.6 to 2.7 which is higher than the specific gravity calculated for the twelve quarries shown in table (26) to table (37) which is ranging between 2.44 to 2.64. The value of the specific gravity of aggregate is not always a measure of its quality.

The water absorption of aggregates is found by calculating the increase in weight of an oven-dried sample after it has been soaked in water for 24 hours according to the ASTM C 127 specification, expressed as percentage of increased weight to the weight of dry sample.

Absorption for crushed limestone [10] ranges between .5 to 1%. The twelve quarries test samples table (26) to table (37) yielded an absorption capacity in the range between 1.2

to 7.58%. This indicate that most of the aggregates available are highly porous excent the aggregates from quarries No. 11, No. 4 and No. 8. The absorption of the aggregate influences such properties as the bond between the aggregate and the cement paste, the resistance of concrete to freezing and thawing as well as its chemical stability and resistance to abrasion. Also the absorption capacity is a measure of the porosity of an aggregate.

There is no clear relation between the strength of concrete and the water absorption of aggregate, but the pores at the surface of the particle may affect the bond between the aggregate and the cement paste and hence may influence the concrete strength. The absorped water by the aggregates according to their absorption capacities should be added to the net water required for the mix.

The fine aggregate specific gravity and absorption are found according to ASTM C 128 specification. The results are tabulated in table (38). The fine aggregate has a specific gravity of 2.64 and an absorption capacity of 0.2% by weight. The approximate absorption capacity of sand is in the range of 0-2%.

3.5.5 Los Angeles Abraison Test, ASTM C 131

The Los Angeles test is one of the important tests that shows the quality of aggregates. The aggregates with specified grading is placed into a cylindrical drum where steel balls are hitting the aggregate while the drum rotates. This test is done according to the ASTM C 131 specification. The result of this test is a good guide not only for the actual wear of aggregates when used in concrete but also of the compressive strength of concrete made with the given aggregates.

In the ASTM C 33 the maximum allowed abrasion loss for crushed stone is 50%. Limestone crushed aggregate [10] has an average abrasion of 16.5%. The twelve quarries test samples showed a wide range of abrasion loss listed in Table (39) to Table (50). The maximum abrasion loss recorded was for quarry No.2 equal to 48.52%, and the minimum abrasion loss recorded was for quarry No.11 equal to 20.94%. The average abrasion loss is 35%. This wide range of variation in the abrasion of the aggregates available leads to the conclusion that the quality of aggregates obtained from the different quarries in the Eastern Zone varies a great deal and that one should be quite selective in choosing the quarry from which one gets the crushed aggregates for concrete production.

3.5.6 Soundness of Aggregates, ASTM C 88

The soundness test is performed to measure the volumetric expansion which some clayey limestones may undergo because of weathering or reaction with chemical elements in concrete. The test is done according to the ASTM C 88 specification by alternate imersion and drying of the sample of aggregates in a sodium or magnesium sulfate solution for five cycles. The amount and type of disintegration resulting from this cyclic treatment is determined.

The crushed stone maximum soundness (11) loss allowed by weight is 12% if sodium sulfate solution was used and 18% if magnesium sulfate solution was used. The twelve quarries test samples yield wide range of soundness. The maximum loss was 20.81% for quarry No.2 which is not acceptable according to specifications and the minimum loss was 1.23% for quarry No. 11. The results are tabulated in table (51) to table (62). As for the qualitative examination the percentage of cracking and splitting for each sample is shown in the above mentioned table. None of the samples showed serious distress in cracking and splitting.

3.5.7 Clay Lumps and Friable Particles, ASTM C 142

Clay lumps and friable particles in the form of surface coating prevent good bond between cement paste and aggregates and cause concrete to expand and contract excessively thus leading to cracking. Also they increase the water requirement for the mix.

The ASTM C 33 maximum limit for clay lumps and friable particles is 5% by weight. The amounts of these deleteterious substances in the coarse aggregates were determined for the three best test samples. Results tabulated in table (63) to table (65) show that the maximum amount is 1.83% for quarry No. 7 and the minimum is .48% for quarry No.11 which is below the maximum allowed limit. The fine aggregate contained 0.03% of clay, lumps and friable particles as shown in table (66).

3.5.8 Petrographic Examination of Aggregates for Concrete, ASTM C 295

A thin section of the original rock of quarry No.8 was prepared in the geology laboratory. Microscopic test of this section showed that the rock contain 95 to 98% calcium carbonate and a little magnesium. The rest of the constituents of the rock is about 2% of scattered sand grains. Also there might be a trace of dolomite.

The particles shape of the rock are subrounded to slightly sub-angular. The way the grains interlock show that this is a very dense rock i.e. extremely nonporous. The color of the grains is light tan.

3.5.9 Test for Compressive Strength of Coarse Aggregates Cubes

Two specimens of the original rock sample from quarry No.8 were cut into cubical shape. Both specimens were tested under compression. Results in table (67) show that the rock sample has an average compressive strength of 8502 psi. This value is much lower than the average compressive strength of the American and the British limestone commonly used as concrete aggregates which is 23,000 psi and 24,000 psi respectively.

3.5.10 Contaminated Soluble Salts, PH Value, Hardness and Alkalinity of Coarse Aggretes

In dolomitic limestone deposits salt concentration usually increases toward the surface. Some of the contaminants found in the coarse aggregates for quarry No.8 which is selected for concrete mix are listed in table (68). These amounts show that for this particular quarry the contamination is low.

Salt contamination could lead to the following:

a) Salt will absorb moisture from the air and cause unsightly white deposits on the surface of the concrete.

b) A slight corrosion of reinforcement may result.

Contamination is reduced almost to 80% by adopting the following steps:

a) Removal of the surface rock

b) Selection of clean, hard rock which is free from visible salt and filled cavities.

c) The process of choosing the rock should be done by trained, well experienced person to avoid weaker and contaminated rocks.

d) Washing the produced aggregates and protecting them from further contamination while stored in a stock pile at the crusher or at the job site.

3.6 Evaluation of Various Quarries

Careful study of the different results of tests performed on the aggregate samples from the twelve qurries leads to the following conclusions:

1) The aggregates from quarries No. 8 and No. 11 are considered the best. This is due to the fact that their aggregates showed the least abrasion, absorption and the highest soundness and unit weight.

2) Quarry No. 2 has the lowest quality aggregates. It had the highest abrasion. Its percent wear (48.5%) barely meets the ASTM requirement of a maximum percent wear of 50. Its weighted percentage loss in the soundness test was 20.8% while the accepted maximum according to ASTM is 12%.

3) With the exception of querries No.8 and 11 that provide good quality aggregates and quarry No.2

that has the lowest quality aggregates, the rest of the quarries generally in the Dhahran area provide aggregates that are almost of equal quality.

4) It is to be noticed that the best aggregates come from quarry No.8 and the worst aggregates come from quarry No.2 and both are located at the Hofuf area. Thus one cannot generalize that good aggregates or bad ones come from this or that location. It depends on the particular quarry and each one has to be investigated seperately since veins of rocks change a great deal in quality from one quarry to another.

5) Good management and experienced personnel in the quarries is very essential to get good final crushed aggregate products. This is especially in regard to the grading and washing of the aggregates and the avoidance of soft rocks or salty ones. It is noted that quarry No.12 has experienced personnel and a testing laboratory to control daily production.

6) The best two quarries in terms of their quality were chosen for concrete mixes which are quarries No. 11, 8. It was decided to choose the third quarry as the best in the Dhahran area since it represent the largest area in aggregate production. This turned to be quarry No. 7.

4. CONCRETE STRENGTH OPTIMIZATION

4.1 Need and Application of High Strength Concrete

In recent years interest in good quality concrete and specially high strength concrete is increasing rapidly. Application of high strength concrete in the construction industry with its present advanced technology is becoming wide spread. High strength concrete is recommended where architectural considerations require more slender vertical load carrying elements reducing the columns sizes to increase the usable space. High strength concrete is also applied widely in prestressed concrete construction because of the technical and economic advantages that can be achieved by the utilization of higher strength in design. In prestressed concrete, using high strength steel requires the use of higher strength concrete. A 6000 psi concrete is the normal strength specified in the prestressed concrete industry. Also high strength concrete leads to reduction in creep and shrinkage.

In prestressed concrete high strength concrete of 6000 psi to 8000 psi are being specified for the following uses:

a) In prestressed concrete bridge girders, the higher strength permits longer spans or fewer girders per span.

b) In prestressed concrete piles and compression members, where the load-carrying capacity is directly proportional to the strength, the cross section of the member is made much smaller.

c) Prestressed concrete railroad ties also used high strength concrete.

4.2 Materials Selection

The selection of materials for concrete making is not easy, since many variables affect the quality and strength of the concrete produced, and both quality and economy must be considered. The qualities required for a structure are generally, strength and durability. In fact there are no special materials required to produce high strength concrete, only one needs to examine the factors affecting concrete compressive strength and to vary those factors for the best results.

In this study each factor was analyzed separately in developing the mix. As soon as an optimum procedure is reached for each variable, that procedure is then incorporated while the other variables are studied.

In the following sections a description of the materials used and their properties that affect quality, and strength of concrete are considered.

4.2.1 Cement

Selection of Portland cement is usually based on comparative strength tests of concrete tested at 28 days and 90 days, also by measuring the compressive strength of 2 in. cubes of cement mortar, (ASTM C109). Cement which yields higher strength at extended ages is generally better. Some types of cements are specified for certain reasons, such as, low alkali Type II is used whenever the aggregates are highly reactive with alkalies. The high-early strength cement Type III gains strength faster than the ordinary cement Type I.

The deleterious effect of sulphates on concrete is due to the attack of sulphate salts on the calcium aluminate (C_3A) in the cement. One obvious means to stop the attack would be to suppress the formation of this compound in the cement. This had been achieved by manufacturing cement with special raw materials so that it has minimum content of C_3A. In Saudi Cement Type V which is sulphate resistant cement, the C_3A content is 0.06% while the maximum allowed by ASTM C150 is 5%. This puts Saudi Cement produced in the Eastern Province as one of the leading cement in resisting sulphate attack. The low C_3A contents means that it has a high silicate content and this gives the cement a high strength[10]. Also another advantage of using the sulphate resisting cement is that it generates lower heat of hydration than ordinary cement. Type V cement has low alkalies content of 0.38% (which is lower than the maximum allowed by ASTM C150 of 0.6%) and that is safer when used with aggregates of undetermined alkali potential reactivity.

The cement testing certificate of Type V obtained from the factory (Appendix C) when compared with the limits specified in ASTM C150 shows that the Saudi Cement Type V meets the requirements of these specifications. Type V cement is the only kind produced in the Eastern Province, but regarding its characteristic, it can be classified as ideal for the local conditions where the soil has high salt content.

Generally high strength concrete is achieved by using high cement content. Trial mixes were designed with different cement factors. The cement content varied between 650 pounds per cubic yard to 940. Figure (22) shows that the concrete compressive strength increases with the increase in cement content. When the cement factor increased from 7 to 10, the gain in compressive strength is 15%. Actually this gain in strength should be justified against the additional cost.

In spite of the fact that this study is mainly concerned with the local material an additional mix was made with the Japanese Cement Type I for comparison. Results in Table (100) shows that the Saudi Cement Type V provides higher strength than the Japanese cement. Table (103).

4.2.2 Coarse Aggregate

Three quarries, No. 7, 8, and 11 were selected for their high performance on the quality evaluation tests as explained in the previous chapter. Trial concrete mix which is using aggregates from quarry No.8 has the highest compressive strength as shown in Figure (23).

Coarse aggregate should be washed to remove fines which absorb more water and reduce the workability of concrete. In the laboratory the coarse aggregates were used at saturated surface dry condition by presoaking them in water for 24 hours and then by rolling them in a large absorbent cloth until all the visible films of water are removed. In industry there are special machines for aggregate washing. This method beside the advantage of cleaning the aggregates it reduces the slump loss that would normally occur with dry high absorbtive aggregates. Results show that there is a considerable increase in the concrete compressive strength with washed coarse aggregates mix compared to the unwashed mix as shown in Figure (24). There is a gain in the 28 days strength of 24% due to the process of washing the aggregates.

The effect of maximum aggregate size was studied. Figure (25) shows results of tests made using 3/8, 1/2, and 3/4 - inch maximum size aggregate. The test results show that the 3/8-inch aggregate gives the highest strength. This is explained because the smaller aggregate has more surface area, and subsequently higher bond strength than larger aggregates.

The aggregates available from local quarries are poorly graded and do not in general meet the ASTM Specification for gradation. Thus it was decided to grade the aggregate within the middle range of the ASTM C33 grading limit as shown in Figure (19).

4.2.3 Fine Aggregates

One of the most important factors of using sand in concrete is that it provides workability. The sand particle shape, and surface texture have a great effect on the water demand and the concrete compressive strength of the mix. It is advisable to have a minimum of fines passing the No.50 and 100 sieves in the range of 10-30% and 0-10% respectively. These fines create a higher water demand resulting in lower strength and greater shrinkage.

Most of the sand used in the Dhahran Area comes from the sand dunes in the Half-Moon bay. It is preferable to use round, smooth, and coarse fine aggregate particles. The availability of such fine aggregates are not abundant. It is thus necessary to get the sand from the windward face of

The sand dune. The sand particles are coarser in this side than the leeward direction because the wind blows the finer particles over to the other side. This process is illustrated in Figure (26).

The sand used in the concrete mix is exceptionally good relative to the available one. It has a fineness modulus of 2.7 and a gradation limit which almost meets the ASTM C 33 limits. (see 3.6.1).

The sand/aggregates ratio is discussed in the mix optimization, article 4.4.

4.2.4 Admixture

Increased use and extensive study of water reducing admixtures are taking place these days. Generally admixtures are used to improve concrete strength, workability, finishability, and uniformity. Water reducing admixtures will produce a workable mix that has lower water cement ratio which generally produces stronger concrete.

Water-reducing retarders admixtures are classified into three classes as follows:

a) Salts of sulfonated ligning which are a waste product from the paper industry used to reduce water.

b) Salts of hydroxy acids used to induce bleeding.

c) Hydroxylated polymers, which are used in the concrete mix optimization and are described in following paragraph.

Hydroxylated polymers were first introduced in the market in 1965. Commercially they are designated by Pozzolith 100 series, Pozzolith 200 series, and so on. There are several advantages for using hydroxylated polymers such as:

a) Hydroxylated polymer admixtures improve workability, handability, placeability and moldability.

b) They improve the finishability.

c) They produce the best uniformity (least variation) in concrete strengths.

d) They reduce or alleviate segregation problems in the mix.

e) They in general reduce the total water content by about 10% to 15%.

Three types of hydroxylated polymers admixtures were used in the concrete mix optimization which are:

a) Pozzolith 300-N

b) Pozzolith 748-ME

c) Rheomac 716

The mixes where the admixtures effects were tested had a W/C of 0.30, while all the other tests had a W/C of 0.35. For comparison, a special mix also with W/C of 0.3 (mix # 19) was tested without any admixtures. The behavior of the concrete mix varied differently with each type of admixture. Mix No. 16 is using Type 300-N admixture which showed the following results compared to the basic mix No.19 (see table 105).

1) The mix workability improved, slump increased from zero to 2-inch.

2) 28 days concrete compressive strength increased by 10%.

3) Concrete strength is uniform. The variation in the results between the three cylinders tested was minimal.

Mix No.17 is using Type 748-ME admixture which showed the following results compared to the basic mix No.19 (see table 106).

1) The 28 days concrete compressive strength increased by 15%.

2) The mix workability improved, slump increased from zero to .75 inch.

3) Concrete strength is uniform.

Mix No.18 is using Rheomac 716 admixture which showed the following results compared to the basic mix No.19 (see table 107).

1) High increase in the workability, slump increased from zero to 11-inch.

2) Low increase in the strength 5%.

4.2.5 Mixing Water

The quality of water used for the concrete mix is very important because impurities in the water may interfere with the setting of the cement, affecting the strength of concrete or causing stains on its surface, and may also lead to corrosion of the reinforcement.

Most specifications [10] give a simple method to check the suitability of water for concrete mix and that is by its fitness for drinking. Also water which does not taste saline or brakish is suitable for use.

Specifications [10] put the restriction, that water that is used in concrete mix should not have dissolved solids in excess of 2000 ppm (parts per million). Also chloride should not exceed 500 ppm and sulphates should not exceed 1000 ppm. Appendix (E) shows that the water used for concrete mixing in the laboratory of the University of Petroleum and Minerals in Dhahran meets the specifications. It has 792.8 ppm dissolved solid, 241 ppm chloride, and 233 sulphates. It is recommended to use cool water [2] for mixing (40°F) instead of normally warm water (70°F) because cooler water produces a gain in slump of 1 to 2 inches, thus one is able to reduce the amount of water.

4.3 Mix Design

Mix design is the process by which the relative amount of the various ingredients of a concrete mix is determined. Proportioning may be entirely empirical based on experience and observation, or it may be based on some recommended methods and calculations.

Two conventional methods were used in this study to design the concrete mix. The first is the American Concrete Institute (ACI) method for determining the mix proportions. The second is the absolute volume method.[10] Both methods and the advantages of each are explained in sections (4.3.1 and 4.3.2).

Since the objective of this study was to reach an optimum concrete compressive strength, all the materials were selected after careful study and all of them meet the limits required by the specifications. The factors that affect the concrete compressive strength were varied for best results. Each variable was analyzed seperately in developing the mix design. When an optimum or near optimum procedure is reached for each variable, the procedure is then adopted while the other variables are studied.

Since the major concern of this study was to reach high strength concrete, all tests made employed a high cement content and very low water cement ratio.

4.3.1 ACI Method

American Concrete Institute (ACI 211.1.74) developed a method of proportioning concrete materials to produce mixes of desired properties. The ACI method of proportioning depends on data tabulated from observations of a large number of trial mixes. Six tables are given to aid in mix proportions. To use these tables one should have the following information:

fineness modulus of fine aggregate,
maximum size of coarse aggregates,
unit weight of dry-rodded coarse aggregate,
and specific gravity of aggregates

The procedure of the ACI method consists of the following:

1) Select a slump appropriate to the conditions of placing concrete. In this study a 2-inch slump was chosen.

2) Maximum size of aggregate recommended for the type of construction is selected. In this study 3/4, 1/2, 3/8 inch aggregate maximum size were tested to select the size which gives the optimum strength.

3) Total free water (pounds per cubic yard) is then selected from the table provided by the ACI based on the slump and aggregates' maximum size previously selected. That table also gives the approximate amount of entrapped air.

4) Water cement ratio is then selected from another table based on a designed compressive strength of 5500 psi.

5) Cement content is computed by dividing the total free water content by the water-cement ratio.

6) The bulk volume of dry-rodded coarse aggregate per unit volume of concrete is taken from a third table based on the coarse aggregate maximum size and the fineness of fine aggregate.

7) The solid volume of sand is computed by subtracting from the total volume of concrete the solid volumes of cement, coarse aggregate, water, and entrapped air.

8) Batch quantities are computed on the basis of dry aggregates and then converted into conditions of the materials as batched at the job.

Concrete mix design data employing the ACI method is presented in a tabular form for the first five mixes from table (70) to (74). In all mixes designed by the ACI method the design compressive strength was met and exceeded with the exception of mix No.1. The ACI method provides a simple method for mix proportioning especially with the availability of the aggregates testing data. It was found that the ACI method yields very high percentage of fine aggregates in the original five mixes. For example in mix No. 5 the percentage was 55%. Basically the ACI method should be employed for ordinary concrete, and not for high strength concrete.

4.3.2 Absolute Volume Method

The use of the ACI proportioning method yielded very high fine aggregate content and in general, to achieve higher strength concrete the ratio of fine aggregate to coarse aggregate should be in the range of 0.3 to 0.5. This led to the adaption of the absolute volume method which proved to be quite satisfactory in the remaining mixes. This method is based on the knowledge of water/cement ratio, cement content, sand-aggregates ratio, and specific gravity of the different materials.

The basic formula assumes that the total volume of the concrete material including the air is equal to one cubic yard. With the knowledge of the weight of cement and water one can get the weight of the total aggregates. Also with the knowledge of sand/aggregates ratio, the weight of each can be calculated. Batches quantities are then reduced to the desired volumes and weights. Mix No.6 to 20 design data and batches quantities are shown in table Nos.75 to 89.

4.4 Mix Optimization

Concrete materials had been studied and their characteristics were analyzed in the previous sections. Incorporation of the recommendation that was discussed previously that affects the concrete strength will result finally in the optimum mix. The steps taken to reach the optimum mix were as follows:

1) Quarry selection
2) Determination of the best maximum aggregate size.
3) Varying the cement factor.
4) Optimum ratio of sand to coarse aggregates is determined.
5) Aggregate washing.
6) Use of admixtures.

Small matrix was designed for the developing the optimum mix as shown in the chart, Figure (27).

Since the study is concerned with high strength concrete, the water/cement ratio was kept at 0.35. The first three mixes designed according to the ACI method to choose the best aggregate source. The result showed that aggregates from quarry No. 8 gave the best 28 days compressive strength as shown in table 91 (see figure 23). The maximum aggregate size used in this comparison was kept constant and it was choosen as 3/4".

The next step was to choose the maximum aggregate size which gives the best compressive strength. Mixes numbers 2,4 and 5 were designed according to the ACI method. The results showed that 3/8 inch maximum size aggregate gave the best 28 days compressive strength. Since the ACI method yields very high sand content, it was decided to adapt the absolute volume method. Mixes Nos.6,7 and 8 were designed using the absolute volume method and changing the maximum aggregate size, while keeping the water/cement ratio of .35 and the sand/aggregate ratio of 0.35 and the cement factor of 8 constant. The results showed that the 3/8 inch maximum size aggregates gave the highest 28 days compressive strength as shown in table (96), and (97), (see figure 25). Reference (16) shows that higher strength can be obtained by using 1½-inch maximum size aggregates.

Mixes Nos. 8,9,10 and 11 were designed with different cement factors while keeping the other variables constant. The results in table (98), (99), (100) and Figure (22) show that mix No. 11 which contain the highest cement factor has the highest 28 days compressive strength. The same conclusion was obtained in Ref.(2), but the opposite result was obtained in ref. 14 and 15. At this stage, the strength gain should be justified against the additional cost of using high cement content. The effect of cement content on the compressive strength of concrete is shown in Figure (22).

Sand/aggregate ratio was varied in mixes Nos. 11, 12 and 13 at the ratios of .35, .3, and .4 respectively. Figure (28) shows that the sand/aggregate ratio of .35 gives the highest 28 days compressive strength.

In mix No.14 the brand and type of cement was changed. Japanese Cement Type I was used. Table (103) shows that the 28 days compressive strength is 29% lower than 28 days compressive strength of mix No.11 where Saudi Cement Type V was used. Many times imported cements are not properly handled or stored and get exposed to high humidity which causes part of the cement to set. Thus freshly made Saudi cement renders better results.

There is a considerable increase in the strength of concrete due to the aggregate washing. Figure (24) shows the effect of aggregate washing. Mix No.11 shows a gain in strength of 24% relative to mix No.15 of unwashed aggregates.

Three types of admixtures were used in mixes Nos. 16, 17 and 18. All the variable were kept unchanged except the water cement was reduced to 0.3. (Mix No. 19 was designed with the same condition to serve as a reference). Results in

Figure (30) show that mix No. 18 gives the highest 28 days compressive strength. Gain in compressive strength and workability by using admixtures should be justified against the additional cost.

Mix No.20 was designed using natural gravel from Riyadh for comparison purpose. Table (109) shows that the 28 days compressive strength is lower (6651 psi) than the strength attained with mix No.11 (8183 psi). This is explained by the fact that the natural aggregates are always weathered which causes the aggregates to be smoother and hence the bond between the aggregate and the cement paste is not as strong as in the case of crushed stones that has rough surfaces.

The result of this optimization study showed that mix No. 11 had the highest 28 days compressive strength which was 8183 psi. Mix No. 17 in which admixtures were used had a 28 days compressive strength of 8340 psi. Hence the use and application of admixtures should be justified according to the design strength required, quality of material available, workability required and the job condition before using them. The cost and the recommended dosages of the admixture used is shown in Appendix (D).

4.5 Description of Laboratory Equipments and Methods Used for Mixing, Molding, and Curing

Concrete is mixed for 2 minutes in a four cubic feet Gustav Eirich mixer. The coarse and fine aggregates are transferred to the mixer in a saturated surface-dry condition. The solid materials were added simultaneously. The water was added then at a constant rate. Admixtures were added at the final stage with the last part of the water. It is preferable to use cool mixing water if it is available. Temperature of the mix was in range of 23^{o}C to 25^{o}C.

Concrete is placed in a cylindrical mold 6 x 12-inch. The concrete was placed in three layers. It was vibrated thoroughly at the level of each layer. After the third layer was vibrated the surface of the cylinder was smoothed. The cylindrical molds were opened after 24 hours.

The concrete cylinders are then labelled with the mix number and the molding date and the breaking date then they are immersed in a water bath for curing until the breaking date. The concrete should be in high humidity medium so that the hydration process between cement and water takes place.

4.6 Testing

Concrete cylinders are tested for compressive strength according to the ASTM C39 specification. The specimen is capped by a thin layer of a capping compound of uniform thickness. The capping compound should be of good quality sulfur specially made for high strength concrete. The advantage of capping is to provide a horizontal smooth surface for testing.

The concrete cylinder must be properly centered in the testing machine. High strength concrete cylinders explode on breaking. Therefore a protective screen or board were used to surround the testing machine so that the operator and the equipments in the laboratories are protected.

The concrete cylinders were crushed to failure. It was noticed that the failure is partly in the cement-aggregate inter face and partly by fracturing the aggregates themselves. Most of the concrete cylinders broke into two conical ends sections.

5. CONCLUSION AND RECOMMENDATIONS

The following conclusions and recommendations are drawn from the aggregate study.

1) Good quality aggregates are found in quarries No.8 in the Hofuf area and quarry No. 11 and 4 in the Safania area. In the Dhahran area where the majority of the quarries exist quarry No. 7 gave the best results on its aggregates although less in quality than the above mentioned quarries.

2) Aggregate quality from each quarry should be routinely tested and data should be recorded to compare their performance.

3) The quarries operating in Al-Agrabia area are surrounded by residential area. This is not good in terms of safety, health, and appearance. Thus it is highly recommended that these quarries should be stopped and the plants shifted to a more suitable place.

4) The aggregates in most quarries available are poorly graded, so it is recommended to regrade them.

5) In each quarry there should be an experienced person who can manage the plant and control the quality of production.

6) Test results showed that all quarries investigated, with the exception of quarry No.2, meet the limits of concrete aggregate specification ASTM C 33.

The following conclusions and recommendations are dranw from the concrete optimization study:

1) Aggregates taken from quarry No.8 gave the highest 28 days compressive strength (5756 psi) compared to quarry No.7 (4860 psi) and quarry No. 11 (5622).

2) Maximum aggregate size of 3/8 inch proved to give the highest 28 days compressive strength of 7586 psi compare to 3/4 inch (6458 psi) and 1/2 inch (6664 psi).

3) The increase in cement content leads to an increase in strength. A mix with cement factor of 10 (940 pounds of cement) gave the highest 28 days compressive strength (8183 psi) compared to cement factors of 7, 8 and 9.

4) The mix with sand/aggregate ratio of 0.35 showed

the highest 28 days compressive strength (8183 psi) compared with sand/aggregate ratio of 0.3 (6858 psi) and 0.4 (6313 psi).

5) The mix with fresh Saudi Cement Type V showed a higher strength (8183 psi) compared to the imported Japanese Cement Type I (5846).

6) Washing the coarse aggregates is a must to remove all the contaminants and the coating materials such as silt and dust. The mix with unwashed aggregates showed a 24% decrease in strength and 87.5% decrease in slump.

7) Using admixtures gave the optimum mix with 28 days compressive strength of 8340 psi compared to a similar mix with no admixture (7091 psi). Also there was considerable gain in the workability.

8) Natural coarse aggregate from Riyadh area gave a 28 days compressive/strength of 6651 psi compared to 8183 psi obtained by using crushed aggregates with the same mix proportions.

9) Mix No. 11 was the optimum mix with 28 days compressive strength of 8183 psi. In this mix water cement ratio of 0.35, sand/aggregate ratio of 0.35, and cement

factor of 10 were used. Admixtures were not used in this mix.

10) The optimum compressive strength achieved was 8340 psi which is almost equal to the compressive strength capacity of the aggregate which has an average compressive strength of 8500 psi and the aggregates themselves fractured when the concrete cylinders were tested. This shows that in this study the ultimate capacity was reached.

11) The use of high cement factor in mixes No.11 (8183 psi) and No.17 should be justified against the additional cost. Nevertheless one can achieve quite a high strength up to 7200 psi with 7 bags of cement per cubic yard which is quite a reasonable cement content and not too costly or prohibitive.

12) In this study, methods of obtaining high strength concrete were explored, and it was concluded that high strength can be achieved by using the local available materials. Prestressed and precast industry does not have a hinderance to start and to contribute its best in this area. An industry badly needed for the advancement of the rapid construction and housing projects that are taking place in the development plans of Saudi Arabia.

Strength of concrete is generally a good index for its durability, however the durability of locally made concrete is still a field that has to be further investigated. It is recommended that more research should take place in the field of concrete durability.

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Table-1 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 1 Total Weight 12000 gms.

Location Dhahran Area Date 16/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25				100
3/4"	19	1654.5	13.99	13.79	6.21
3/8"	9.5	8165.5	68.05	81.84	18.16
No. 4	4.75	2024.5	16.87	98.71	1.29
No. 8	2.36	84.5	.71	99.42	.58
PAN		70.1	.58	100	

Table-2 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 2 Total Weight 12000 gms

Location Hofuf Area Date 16/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25				100
$\frac{3}{4}$"	19	230	1.92	1.92	98.08
$\frac{3}{8}$"	9.5	10256	85.57	87.49	12.51
No. 4	4.75	1458.5	12.17	99.66	.34
No. 8	2.36	10.5	.09	99.75	.25
PAN		30.5	.25	100	

Table-3 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 3 Total Weight 14602 gms

Location Dhahran Area Date 17/2/1978

Aggregate max. size 1" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	1453	9.97	9.97	90.03
$\frac{1}{2}$"	125	12413.0	85.20	95.17	4.83
No.4	4.75	614.5	4.22	99.34	.61
No.8	2.36	4	.03	99.42	.58
PAN		84.5	.58	100	

Table-4 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 4 Total Weight 12884 gms

Location Safania Area Date 18/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	28	.22	.22	99.78
3/4"	19	7232	56.27	56.49	43.51
3/8"	9.5	5483.5	42.67	99.16	.84
No.4	4.75	7	.05	99.21	.79
No.8	2.36	4	.03	99.24	.76
PAN		97.5	.76	100	

Table-5 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 5 Total Weight 12000 gms

Location Dhahran Area Date 18/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	249	2.08	2.08	97.92
3/4"	19	3089	25.76	27.84	72.16
3/8"	9.5	7800.0	65.04	92.88	7.12
No.4	4.75	782.0	6.52	99.4	.6
No.8	2.36	4.5	.04	99.44	.56
PAN		68.5	.56	100	

Table-6 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 6 Total Weight 12460 gms

Location Dhahran Area Date 19/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25				100
$\frac{3}{4}$"	19	266.0	2.14	2.14	97.86
$\frac{3}{8}$"	9.5	11702	94.13	96.27	3.73
No.4	4.75	374.5	3.01	99.28	.72
No.8	2.36	5	.04	99.32	.68
PAN		84.5	.68	100	

Table-7 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 7 Total Weight 13180 gms

Location Dhahran Area Date 19/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	112.5	.85	.85	99.15
3/4"	19	4125	31.30	32.15	67.85
3/8"	9.5	8652	65.65	97.8	2.2
No. 4	4.75	79	.6	98.4	1.6
No. 8	2.36	70	.53	98.93	1.07
PAN		141	1.07	100	

Table-8 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 8 Total Weight 13233 gms

Location Hofuf Area Date 19/2/1978

Aggregate max. size 1" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	737	5.57	5.57	94.43
½"	12.5	12431	93.94	99.51	.49
No. 4	4.75	15	.11	99.62	.38
No. 8	2.36	5	.04	99.66	.34
PAN		45	.34	100	

Table-9 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 9 | Total Weight 13720 gms

Location Al-Agrabia Area | Date 20/2/1978

Aggregate max. size 1" | Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	43.5	.32	.32	99.68
$\frac{3}{4}$"	19	4410	32. 17	32.49	67.51
$\frac{3}{8}$"	9.5	9079	66.23	98.72	1.28
No.4	4.75	19.5	.14	98.86	1.14
No.8	2.36	6	.04	98.90	1.1
PAN		1505	1.1	100	

Table-10 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 10 Total Weight 12464 gms

Location Al-Agrabia Area Date 20/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25				100
3/4"	19	746.5	6.0	6.0	94
3/8"	9.5	11394	91.55	97.55	2.45
No.4	4.75	239.5	1.92	99.47	.53
No.8	2.36	4.5	.04	99.51	.49
PAN		62.0	.5	100	

Table-11 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 11 Total Weight 13733 gms

Location Safania Area Date 20/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	68.5	.5	.5	99.5
$\frac{3}{4}$"	19	4946.5	36.12	36.62	68.38
$\frac{3}{8}$"	9.5	8411.0	61.43	98.05	1.95
No.4	4.75	180	1.32	99.37	.63
No.8	2.36	6.5	.05	99.42	.58
PAN		80.5	.59	100	

Table-12 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 12 Total Weight 15618 gms

Location Dhahran Area Date 21/2/1978

Aggregate max. size 3/4" Tested by

Sieve No.	Diam (mm)	Wt. Retained gms	% Retained	Cummulative % Retained	% Passing
1"	25	82	.53	.53	99.47
3/4"	19	2941	18.83	19.36	80.64
3/8"	9.5	11570	74.08	93.44	6.56
No.4	4.75	865	5.54	98.98	1.02
No.8	2.36	58	.37	99.35	.65
PAN		102	.65	100	

Table-13 GRAIN SIZE ANALYSIS (ASTM C136)

Quarry No. 13 Total Weight 500 gms.

Location Half-Moon Date 2/5/1978

Aggregate Max. Size No. 8 Tested by

Sieve No.	Diam (mm)	Wt. Retained gms.	% Retained	Cummulative % Retained A	% Passing
4	4.75	-	-	-	100
8	2.36	0.1	.02	.02	99.98
16	1.18	6.0	1. 2	1.22	98.78
30	0.59	374.8	74.96	76.18	23.82
50	0.30	76.9	15.38	91.56	8.44
100	0.15	24.1	4.82	96.38	3.62
PAN		18.1	3.62	-	-
Total		500		266	

FINENESS MODULUS $= \frac{A}{100} = 2.7$

Table-14 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 1 Date 16/ 2/ 1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	13.06 kg
Unit Weight = D x C	=	1380.96 kg/m^3 (86.2 $lb/ft.^3$)

Table-15 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 2 Date 16/2/1978

Location Hofuf Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	13.33 kg
Unit Weight = D x C	=	1409.51 kg/m^3 (87.99 $lb/ft.^3$)

Table-16 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 3 — Date 16/2/1978

Location Dhahran Area — Tested by

Aggregate max. size 1

Capacity of Measure	= 0.01 m^3
Weight of Measure	= 5.05 kg
Weight of Measure + Water	= 14.46 kg
B = Weight of Water	= 9.42 kg
Temperature of Water	= 28. 5 ^oC
A = Unit Weight of Water	= 996.08 kg/m^3
C = Factor of Measure = A/B	= 105.74
D = Weight of Aggregate To Fill The Measure	= 12.62 kg
Unit Weight = D x C	= 1334.44 kg/m^3 (83.3 $lb/ft.^3$)

Table-17 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 4 Date 17/ 2/1978

Location Safania Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28.5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	12.98 kg
Unit Weight = D x C	=	1372.51 kg/m^3 (85.68 $lb/ft.^3$)

Table-18 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 5	Date 17/ 2/ 1978
Location Dhahran Area	Tested by
Aggregate max. size 3/4"	

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28.5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	12.65 kg
Unit Weight = D x C	=	1337.61 kg/m^3 (83.50 lb/ft.^{3})

Table-19 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 6 | Date 17/2/1978

Location Dhahran Area | Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	12.25 kg
Unit Weight = D x C	=	1295.32 kg/m^3 (80.86 $lb/ft.^3$)

Table-20 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 7 Date 18/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	13.35 kg
Unit Weight = D x C	=	1411.63 kg/m^3 (88.12 $lb/ft.^3$)

Table-21 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 8 Date 18/ 2/ 1978

Location Hofuf Area Tested by

Aggregate max. size 1"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	13.86 kg
Unit Weight = D x C	=	1465.56 kg/m^3 (91.48 $lb/ft.^3$)

Table-22 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 9 Date 18/2/1978

Location Al-Agrabia Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^{o}C
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	12.51 kg
Unit Weight = D x C	=	1322.81 kg/m^3 (82.57 $lb/ft.^3$)

Table-23 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 10 Date 20/2/1978

Location Al-Agrabia Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28.5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	12.99 kg
Unit Weight = D x C	=	1373.56 kg/m^3 (85.74 $lb/ft.^3$)

Table-24 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 11 Date 20/2/1978

Location Safania Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28.5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	12.78 kg
Unit Weight = D x C	=	1351.36 kg/m^3 (84.35 $lb/ft.^3$)

Table-25 UNIT WEIGHT OF AGGREGATE (ASTM C 29)

Quarry No. 12 Date 20/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Capacity of Measure	=	0.01 m^3
Weight of Measure	=	5.05 kg
Weight of Measure + Water	=	14.46 kg
B = Weight of Water	=	9.42 kg
Temperature of Water	=	28. 5 ^oC
A = Unit Weight of Water	=	996.08 kg/m^3
C = Factor of Measure = A/B	=	105.74
D = Weight of Aggregate To Fill The Measure	=	13.32 kg
Unit Weight = D x C	=	1408.46 kg/m^3 (87.72 $lb/ft.^3$)

TABLE-26

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 1 Date 16/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	= 3500	g
C = Weight of aggregate in water	= 2098.7	g
A = Weight of aggregate (oven dry)	= 3253.5	g
Bulk Specific Gravity = A/(B-C)	= 2.32	
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	= 2.5	
Apparent Specific Gravity = A/(A-C)	= 2.82	
Absorption[1], percent = (B-A)/A x 100	= 7.58%	

(1) As defined in ASTM C125

TABLE-27

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 2 Date 17/2/1978

Location Hofuf Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	= 3500	g
C = Weight of aggregate in water	= 2093.8	g
A = Weight of aggregate (oven dry)	= 3317.8	g
Bulk Specific Gravity = A/(B-C)	= 2.36	
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	= 2.49	
Apparent Specific Gravity = A/(A-C)	= 2.71	
Absorption[1], percent = (B-A)/A x 100	= 5.49	

(1) As defined in ASTM C125

Table-28

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No.	3	Date	17/2/1978
Location	Dhahran Area	Tested by	
Aggregate max. size	1"		

B = Weight of agg. saturated surface dry	= 3500	g
C = Weight of aggregate in water	= 2085.2	g
A = Weight of aggregate (oven dry)	= 3335.7	g
Bulk Specific Gravity = A/(B-C)	= 2.36	
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	= 2.47	
Apparent Specific Gravity = A/(A-C)	= 2.67	
Absorption[(1)], percent = (B-A)/A x 100	= 4.93	

(1) As defined in ASTM C125

Table-29

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 4 Date 18/2/1978

Location Safania Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3500 g
C = Weight of aggregate in water	=	2127.2 g
A = Weight of aggregate (oven dry)	=	3432.8 g
Bulk Specific Gravity = A/(B-C)	=	2.50
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.55
Apparent Specific Gravity = A/(A-C)	=	2.63
Absorption[(1)], percent = (B-A)/A x 100	=	1.96

(1) As defined in ASTM C125

Table-30

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 5 Date 18/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3100 g
C = Weight of aggregate in water	=	1829.4 g
A = Weight of aggregate (oven dry)	=	2954.3 g
Bulk Specific Gravity = A/(B-C)	=	2.33
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.44
Apparent Specific Gravity = A/(A-C)	=	2.63
Absorption[(1)], percent = (B-A)/A x 100	=	4.93

(1) As defined in ASTM C125

Table-31

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 6 Date 19/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3500 g
C = Weight of aggregate in water	=	2107.1 g
A = Weight of aggregate (oven dry)	=	3367.0 g
Bulk Specific Gravity = A/(B-C)	=	2.27
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.51
Apparent Specific Gravity = A/(A-C)	=	2.67
Absorption(1), percent = (B-A)/A x 100	=	3.95

(1) As defined in ASTM C125

Table-32

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 7 Date 19/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3500 g
C = Weight of aggregate in water	=	2139.9 g
A = Weight of aggregate (oven dry)	=	3405.0 g
Bulk Specific Gravity = A/(B-C)	=	2.5
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.57
Apparent Specific Gravity = A/(A-C)	=	2.69
Absorption(1), percent = (B-A)/A x 100	=	2.79

(1) As defined in ASTM C125

Table-33

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 8 Date 19/2/1978

Location Hofuf Area Tested by

Aggregate max. size 1"

B = Weight of agg. saturated surface dry	=	3500 g
C = Weight of aggregate in water	=	2171.6 g
A = Weight of aggregate (oven dry)	=	3452.0 g
Bulk Specific Gravity = A/(B-C)	=	2.6
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.64
Apparent Specific Gravity = A/(A-C)	=	2.7
Absorption[(1)], percent = (B-A)/A x 100	=	1.39

(1) As defined in ASTM C125

Table-34

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 9 Date 20/2/1978

Location Al-Agrabia Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3500 g
C = Weight of aggregate in water	=	2102.7 g
A = Weight of aggregate (oven dry)	=	3379.3 g
Bulk Specific Gravity = A/(B-C)	=	2.27
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.51
Apparent Specific Gravity = A/(A-C)	=	2.65
Absorption[(1)], percent = (B-A)/A x 100	=	3.57

(1) As defined in ASTM C125

Table-35

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 10 Date 20/2/1978

Location Al-Agrabia Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3500 g
C = Weight of aggregate in water	=	2162.7 g
A = Weight of aggregate (oven dry)	=	3431.9 g
Bulk Specific Gravity = A/(B-C)	=	2.57
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.62
Apparent Specific Gravity = A/(A-C)	=	2.7
Absorption(1), percent = (B-A)/A x 100	=	1.98

(1) As defined in ASTM C125

Table-36

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 11 Date 20/2/1978

Location Safania Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3390 g
C = Weight of aggregate in water	=	2078.4 g
A = Weight of aggregate (oven dry)	=	3349.8 g
Bulk Specific Gravity = A/(B-C)	=	2.55
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.59
Apparent Specific Gravity = A/(A-C)	=	2.64
Absorption[1], percent = (B-A)/A x 100	=	1. 2

(1) As defined in ASTM C125

Table-37

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
(ASTM C 127)

Quarry No. 12 Date 21/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

B = Weight of agg. saturated surface dry	=	3203.0 g
C = Weight of aggregate in water	=	1940.4 g
A = Weight of aggregate (oven dry)	=	3083.3 g
Bulk Specific Gravity = A/(B-C)	=	2.44
Bulk Specific Gravity (Saturated-Surface Dry Basis) = B/(B-C)	=	2.54
Apparent Specific Gravity = A/(A-C)	=	2. 7
Absorption[(1)], percent = (B-A)/A x 100	=	3.88

(1) As defined in ASTM C125

Table-38

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

(ASTM C128)

Quarry No.	13	Date	3/5/1978
Location	Half-Moon	Tested by	

Aggregate Max. Size No. 8

A = Weight of oven dry specimen in air		=	498.98 gms.
B = Weight of pycnometer filled with water		=	1431. 3 gms.
C = Weight of pycnometer with specimen and water to calibration mark		=	1742. 2 gms.
D = Weight of specimen saturated surface dry		=	500. 0 gms.
Bulk specific gravity	= A/(B+500-C)	=	2.64
Bulk specific gravity (S.S.D)	= D/(B+500-C)	=	2.64
Apparent specific gravity	= A/(B+A-C)	=	2.65
Absorption, percent	= [(500-A)/A]x100	=	0.20

Table-39

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 1 Date 22/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A} x100$
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5 mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.50mm)	2500				
Total	5000	11	500	3144.0	37.12

Table-40

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 2 Date

Location Hofuf Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt. Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	2500				
Total Wt.	5000	11	500	2574	48.52

Table-41

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 3 Date 24/2/1978

Location Dhahran Area Tested by

Aggregate max. size 1"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$1\frac{1}{2}$ in to 1 in (38 - 25 mm)	1250				
1 in to $\frac{3}{4}$ in (25 - 19 mm)	1250				
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5 mm)	1250				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	1250				
Total Wt.	5000	12	500	3301.5	33.97

Table-42

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 4 Date 25/2/1978

Location Safania Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	2500				
Total Wt.	5000	11	500	3328.5	33.43

Table-43

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 5 Date 26/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	2500				
Total Wt.	5000	11	500	3080	38.4

Table-44

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 6 Date 27/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	2500				
Total Wt.	5000	11	500	3107.5	37.85

Table-45

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 7 Date 28/2/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ (12.5 - 9.5mm)	2500				
Total Wt.	5000	11	500	3529.0	29.42

Table-46

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 8 Date 1/3/1978

Location Hofuf Area Tested by

Aggregate max. size 1"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$1\frac{1}{2}$ in to 1 in (38 - 25 mm)	1250				
1 in to $\frac{3}{4}$ in (25 - 19 mm)	1250				
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	1250				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	1250				
Total Wt.	5000	12	500	3852.5	22.95

Table-47

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 9 Date 1/3/1978

Location Al-Agrabia Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5-9.5mm)	2500				
Total Wt.	5000	11	500	3170.5	36.6

Table-48

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 10 Date 2/3/1978

Location Al-Agrabia Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5 mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5 - 9.5mm)	2500				
Total Wt.	5000	11	500	3576.5	28.47

Table-49

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 11 Date 2/3/1978

Location Safania Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19–12.5 mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5–9.5 mm)	2500				
Total Wt.	5000	11	500	3953.0	20.94

Table-50

LOS ANGELES ABRAISION TEST (ASTM C131)

Quarry No. 12 Date 3/3/1978

Location Dhahran Area Tested by

Aggregate max. size 3/4"

Grading Size	Weight Before Test(A) gms	No. of Charges	No. of Rev.	Wt.Retained on # 12 Sieve gms	Percent wear $\frac{A-B}{A}$x100
$\frac{3}{4}$ in to $\frac{1}{2}$ in (19 - 12.5mm)	2500				
$\frac{1}{2}$ in to $\frac{3}{8}$ in (12.5-9.5 mm)	2500				
Total Wt.	5000	11	500	3162	36.76

Table-51

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 1 Date 2/3/1978

Location Dhahran Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	510	14	510	1.96	.28
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	667	68	997	1. 4	0.96
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	330				
$\frac{3}{8}$ in to No.4 (4.75 mm)	300	17	300	4.67	0.79
Total		100			2.03

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ to $\frac{3}{4}$ in (19.00mm)	1	2			2	5			42

Table-52

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 2 Date 9/3/1978

Location Hofuf Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)		2		20.92	0.42
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	671	86	1003	20.92	17.99
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	332				
$\frac{3}{8}$ in to No.4 (4.75 mm)	300	12	300	20	2.4
Total		100			20.81

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	

Table-53

SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULFATE
(ASTM C 88)

Quarry No. 3 Date 16/3/1978

Location Dhahran Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted percentage Loss
$1\frac{1}{2}$ in to 1 in (25 mm)	1021.5	75.5	1524.4	4.24	3.2
1 in to $\frac{3}{4}$ in (19 mm)	503				
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	670	23.98	1007	10.21	2.45
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	337				
$\frac{3}{8}$ in to No.4 (4.75 mm)		.52		10.21	.53
Total		100			6.18

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ to $\frac{3}{4}$ in (19.0mm)	3	5	2	3	4	7			60

Table-54

SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULFATE
(ASTM C 88)

Quarry No. 4 Date 23/3/1978

Location Safania Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	516	57	516	2.36	1.35
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	686	43	686	1.6	.69
Total		100			2.04

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ to $\frac{3}{4}$in (19.0 mm)	1	3			2	6			36

Table-55

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 5 Date 30/3/1978

Location Dhahran Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	502	28	502	4.38	1.23
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	672	65	1002	1.38	0.90
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	330				
$\frac{3}{8}$ in to No.4 (4.75 mm)	300	7	300	6.43	0.45
Total		100			2.58

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ to $\frac{3}{4}$ in (19.0 mm)	1	3			3	9			34

Table-56

SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULFATE
(ASTM C 88)

Quarry No. 6 Date 7/4/1978

Location Dhahran Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)		2		2.1	0.04
$\frac{3}{4}$ in to $1\frac{1}{2}$ in (12.5 mm)	671	94	1001	2.1	1.97
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	330				
$\frac{3}{8}$ in to No.4 (4.75 mm)		3		2.1	0.06
Total		100			2.07

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	

Table-57

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 7 Date 28/4/1978

Location Dhahran Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted percentage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	502	32	502	4.38	1.40
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	670	66	1000	3.5	2.31
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	330				
$\frac{3}{8}$ in to No.4 (4.75 mm)		1		3.5	0.04
Total		100			3.75

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ in to $\frac{3}{4}$ (19.0 mm)	4	8	2	4	2	4			50

Table-58

SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULFATE
(ASTM C 88)

Quarry No. 8 Date 14/4/1978

Location Hofuf Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	502	6	502	.6	0.04
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	670	94	1002	1.3	1.22
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	332				
Total		100			1.26

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ in to $\frac{3}{4}$ (19.0 mm)	1	3			1	3			38

Table-59

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 9 Date 21/4/1978

Location Al-Agrabia Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted per centage Loss
$1\frac{1}{2}$in to $\frac{3}{4}$ in (19.0 mm)	503	33	503	2.59	.85
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	671	67	1001	2.3	1.54
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	330				
Total		100			2.39

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$in to $\frac{3}{4}$ (19.0 mm)	2	5			1	2			42

Table-60

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 10 Date 4/5/1978

Location Al-Agrabia Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted percentage Loss
1 in to 3/8 in (19.0 mm)	503	6	503	5.45	0.33
3/4 in to 1/2 in (12.5 mm)	672	92	1003	2.24	2.06
1/2 in to 3/8 in (9.5 mm)					
3/8 in to No.4 (4.75 mm)		2		2.24	0.05
Total		100			2.44

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ in to $\frac{3}{4}$ (19.0 mm)	1	2			2	4			53

Table-61

SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE
(ASTM C 88)

Quarry No. 11 Date 10/5/1978

Location Safania Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted percentage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	502	37	502	1.55	.58
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	672				
		61.5	1002	1.03	.63
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	330				
$\frac{3}{8}$ in to No.4 (4.75 mm)		1.5		1.03	.02
Total		100			1.23

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ in to $\frac{3}{4}$ (19.0 mm)	1	2			1	2			44

Table-62

SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULFATE
(ASTM C 88)

Quarry No. 12 Date 15/5/1978

Location Dhahran Area Tested by

Sieve Size	weight gms	Grading of original sample percent	Weight of Test Fraction Before Test, gms	Percentage Passing designated sieve after test	Weighted percentage Loss
1 in to $\frac{3}{4}$ in (19.0 mm)	501	20	501	5.6	1.12
$\frac{3}{4}$ in to $\frac{1}{2}$ in (12.5 mm)	671				
		74	1004	4.9	3.63
$\frac{1}{2}$ in to $\frac{3}{8}$ in (9.5 mm)	333				
$\frac{3}{8}$ in to No.4 (4.75 mm)	302	6	302	6.2	0.37
Total		100			5.12

Qualitative Examination of Coarse Size

Sieve size	Particle Fxhibiting Distress								Total No. of Particles before test
	Splitting		Crumbling		Cracking		Flaking		
	No.	%	No.	%	No.	%	No.	%	
$1\frac{1}{2}$ in to $\frac{3}{4}$ (19.0 mm)	1	3			2	7			30

Table-63

CLAY LUMPS AND FRIABLE PARTICLES IN AGGREGATES (ASTM C 142)

Quarry No. 7

Date 20/3/1978

Location Dhahran Area

Tested by

Aggregate max. size 3/4"

Size of Particles Making up Test Sample	Weight of Test Sample gms	Grading of Original Sample percent	Size of Sieve for Removing Residue of Clay Lumps & Friable Particle	Weight After Test gms.	Percent of clay Lumps & Fariable Particle
$\frac{3}{4}$ to $1\frac{1}{2}$ in (19.0 to 3.75mm)	3000	32	No. 4 (4.75 mm)	2961.5	0.41
$\frac{3}{8}$ to $\frac{3}{4}$ in (9.5 to 19.0 mm)	2000	66	No. 4 (4.75 mm)	1960.8	1.29
No.4 to $\frac{3}{8}$ in (4.75 to 95 mm)	1000	1	No. 8 (2.36 mm)	874.6	0.13
Total	6000	100			1.83

Table-64

CLAY LUMPS AND FRIABLE PARTICLES IN AGGREGATES
(ASTM C 142)

Quarry No. 8 Date 15/3/1978

Location Hofuf Area Tested by

Aggregate max. size 3/4"

Size of Particles Making up Test Sample	Weight of Test Sample gms	Grading of Original Sample percent	Size of Sieve for Removing Residue of Clay Lumps & Friable Particle	Weight After Test gms.	Percent of clay Lumps & Fariable Particle
$\frac{3}{4}$ to $1\frac{1}{2}$ in (19.0 to 37.5 mm)	3000	93	No.4 (4.75 mm)	2975.5	.76
$\frac{3}{8}$ to $\frac{3}{4}$ in (9.5 to 19.0 mm)	2000	7	No.4 (4.75 mm)	1944.42	.20
Total	5000	100			.96

Table-65

CLAY LUMPS AND FRIABLE PARTICLES IN AGGREGATES
(ASTM C 142)

Quarry No. 11

Date 25/3/1978

Location Safania Area

Tested by

Aggregate max. size 3/4"

Size of Particles Making up Test Sample	Weight of Test Sample gms	Grading of Original Sample percent	Size of Sieve for Removing Residue of Clay Lumps & Friable Particle	Weight After Test gms.	Percent of clay Lumps & Fariable Particle
$\frac{3}{4}$ to $1\frac{1}{2}$ in (19.0 to 37.5mm)	3000	37	No. 4 (4.75 mm)	2992.0	0.10
$\frac{3}{8}$ to $\frac{3}{4}$ in (9.5 to 19.0mm)	2000	61.5	No. 4 (4.75 mm)	1991.8	0.25
No.4 to $\frac{3}{8}$ in (4.75 to 9.5mm)	1000	1.5	No. 8 (2.36 mm)	916.3	0.13
Total	6000	100			0.48

Table-66

CLAY LUMPS AND FRIABLE PARTICLES IN FINE AGGREGATES
(ASTM C 142)

Quarry No. 13

Date 8/7/1978

Location Half-Moon

Tested by

Aggregate max. size No. 8

Size of Particles Making up Test Sample	Weight of Test Sample gms	Grading of Original Sample percent	Size of Sieve for Removing Residue of Clay Lumps & Friable Particle	Weight After Test gms.	Percent of clay Lumps & Fariable Particle
No. 6 (1.18 - mm)	100	1.22	No.20(850-um)	97.22	0.03

Table-67

COMPRESSIVE STRENGTH TEST OF COARSE AGGREGATE CUBES

Quarry No. 8 Date 16/7/1978

Location Hofuf Area Tested by

Sample No.	Dimension In x In	Load pounds	Compressive Strength psi
1	.78 x .78	6000	9862
2	1.52 x 1.52	16500	7142
Average			8502

TABLE-68 CONTAMINANTS PRESENT IN COARSE AGGREGATES

Quarry No. 8 Weight of Sample = 300 g.

METHOD		
S.M. [1] 112	Chlorides	53 mg/liter
S.M. 122B	Total Carbonate	75 mg/liter
S.M. 122B	Calcium carbonate	59 mg/liter
S.M. 102	Total Alkalinity	36 mg/liter
S.M. 102	PH value	8.5

(1) Ref. (13)

TABLE
69

Summary of Aggregate Tests Results

Quarry No.	Abrasion* % wear	Soundness Weighted % Loss	Soundness Maximum** allowed	Absorption %
1	37.12	2	12	7.58
2	48.52	20.8	12	5.49
3	33.97	6	18	4.93
4	33.43	2	12	1.96
5	38. 4	2.5	18	4.93
6	37.85	2	12	3.95
7	29.42	3.7	18	2.79
8	22.95	1.2	12	1.39
9	36. 6	2.3	18	3.57
10	28.47	2.4	12	1.98
11	20.94	1.2	12	1.2
12	36.76	5.1	18	3.88

* Maximum allowed percentage is 50% (ASTM C 33).

** Depending on the chemical used

Table-70 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	-
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry#13	Source	Quarry No. 7

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64	-	0.2	2.7
Coarse Aggregate	3/4 in	2.57	88.12	2.79	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
1	ACI 211-1-74	0.4	8.38	.46	315	1-2	5500

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0 %	315	787.5	1285.86	1541.74	3930.1
	Cu./Ft.	0.54	5.05	4.01	7.79	9.61	27

BATCHES QUANTITIES PER 1.4 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		16.33	40.83	66.67	79.89	203.72
	Cu./Ft.	.03	0.26	0.21	0.4	.50	1.4

Table-71 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed gravel
Source	Half-Moon, Quarry # 13	Source	Quarry # 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.2	2.7
Coarse Aggregate	3/4 in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
2	ACI 211-1-74	0.4	8.38	0.44	315	1-2	5500

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2	315	787.5	1289.16	1616.77	4008.43
	Cu./ Ft.	0.54	5.04	4.01	9.81	7.83	27

BATCHES QUANTITIES PER 1.4 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		16.33	40.83	66.85	83.83	203.72
	Cu./ Ft.	0.03	0.26	0.21	0.41	0.51	1.4

Table-72 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 11

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.2	2.7
Coarse Aggregate	3/4 in	2.59	84.36	1.2	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
3	ACI 211-1-74	0.4	8.38	0.49	315	1.2	5500

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	315	787.5	1383.25	1452.19	3937.94
	Cu./ Ft.	0.54	5.05	4.01	8.40	8.99	27

BATCHES QUANTITIES PER 1.4 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		16.33	40.83	71.72	75.3	204.18
	Cu./ Ft.	.03	0.26	0.21	0.44	0.47	1.4

Table-73 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No. 8	2.64		0.2	2.7
Coarse Aggregate	1/2 in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
4	ACI 211-1-74	0.4	8.91	.48	335	1-2	550

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	335	837.5	1346.94	1437.12	3956.56
	Cu./ Ft.	0.54	5.37	4.26	8.18	8.72	27

BATCHES QUANTITIES PER 1.4 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		17.37	43.43	69.84	74.52	205.16
	Cu./ Ft.	0.03	0.28	0.22	0.42	0.45	1.4

Table-74 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type		Type	
Brand	V	Brand	

Fine Aggregate		Coarse Aggregate	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No. 8	2.64		0.2	2.7
Coarse Aggregate	3/8	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
5	ACI 211-1-74	0.4	9.13	0.55	350	1-2	5500

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	350	875	1480.64	1206.15	3911.79
	Cu./ Ft.	0.54	5.61	4.45	8.99	7.32	

BATCHES QUANTITIES PER 1.4 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.15	45.37	76.78	62.54	202.84
	Cu./ Ft.	0.03	.29	0.23	0.47	0.38	1.4

Table-75 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	3/4 in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
6	Absolute volume	.35	8	.35	263.2		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	263.2	752	1061.48	1971.31	4047.99
	Cu./ Ft.	0.54	4.22	3.83	6.44	11.97	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		14.62	41.78	58.97	109.52	224.89
	Cu./ Ft.	0.03	0.23	0.21	0.36	0.67	1.5

Table-76 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	1/2 in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
7	Absolute Volume	0.35	8	0.35	263.2		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	263.2	752	1061.48	1971.31	4047.99
	Cu./ Ft.	0.54	4.22	3.83	6.44	11.97	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		14.62	41.78	58.97	109.52	224.89
	Cu./ Ft.	0.03	0.23	0.21	0.36	0.67	1.5

Table-77 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		Coarse Aggregate	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	3/8 in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
8	Absolute Volume	0.35	8	0.35	263.2		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	263.2	752	1061.48	1971.31	4047.99
	Cu./ Ft.	0.54	4.22	3.83	6.44	11.97	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		14.62	41.78	58.97	109.52	224.89
	Cu./ Ft.	0.03	0.23	0.21	0.36	0.67	1.5

Table-78 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No.13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	3/8	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
9	Absolute Volume	0.35	7	0.35	230.3		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	230.3	658	1119.67	2079.39	4087.35
	Cu./Ft.	0.54	3.69	3.35	6.80	12.62	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		12.79	36.56	62.2	115.52	227.07
	Cu./Ft.	0.03	0.21	.19	0.38	0.70	1.5

Table-79 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		Coarse Aggregate	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No. 8	2.64		0.20	2.7
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
10	Absolute volume	0.35	9	0.35	296.1		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	296.1	846	1003.59	1863.8	
	Cu./Ft.	0.54	4.75	4.3	6.09	11.31	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		16.45	47	55.76	103.54	222.75
	Cu./Ft.	0.03	0.26	.24	.34	.63	1.5

Table-80 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No. 8	2.64		0.20	2.7
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.40	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
11	Absolute volume	0.35	10	0.35	329		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	329	940	946.16	1757.16	3972.32
	Cu./Ft.	0.54	5.27	4.78	5.74	10.67	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.28	52.22	52.56	97.62	220.68
	Cu./Ft.	0.03	0.29	.27	.32	.59	1.5

Table-81 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
12	Absolute volume	0.35	10	0.3	329		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	329	940	811.0	1892.32	3972.32
	Cu./Ft.	0.54	5.27	4.78	4.92	11.49	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.28	52.22	45.06	105.13	220.69
	Cu./Ft.	0.03	.29	.27	.27	.64	1.5

Table-82 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No.13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
13	Absolute volume	0.35	10	0.4	329		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	329	940	1081.33	1621.99	3972.32
	Cu./ Ft.	0.54	5.27	4.78	6.56	9.85	27

BATCHES QUANTITIES PER 1. 5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.28	52.22	60.07	90.11	220.68
	Cu./ Ft.	0.03	.29	.27	0.36	0.55	1.5

Table-83 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	I	Type	
Brand	Japanese	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No.13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	27
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
14	Absolute volume	0.35	10	0.35	329		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture	.	Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	329	940	946.16	1757.16	3972.32
	Cu./ Ft.	0.54	5.27	4.78	5.74	10.67	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.28	52.22	52.56	97.62	220.68
	Cu./ Ft.	0.03	0.29	0.27	0.32	0.59	1.5

Table-84 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel *
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
15	Absolute volume	0.35	10	0.35	329		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	329	940	946	1716.36	3931.36
	Cu./ Ft.	0.54	5.27	4.78	5.74	10.58	27

BATCHES QUANTITIES PER 1. 5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.28	52.22	52.5	95.35	218.35
	Cu./ Ft.	0.03	0.29	0.27	0.32	0.59	1.5

* Coarse aggregates are not washed in this mix

Table-85 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	300N
Brand	Saudi	Brand	Master Builders
Fine Aggregate		Coarse Aggregate	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No. 13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No. 8	2.64		0.20	27
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
16	Absolute volume	0.30	10	0.35	282		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
1923	Lbs	2.0	282	940	989.40	1837.47	4048.87
	Cu./ Ft.	0.54	4.52	4.78	6.01	11.15	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
107 C.C	Lbs.		15.67	52.22	54.97	102.08	224.94
	Cu./ Ft.	0.03	.25	0.27	0.33	0.62	1.5

Table-86 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	748ME
Brand	Saudi	Brand	Master Builders
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No.13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	27
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
17	Absolute volume	0.30	10	0.35	282		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
1080 C.C.	Lbs	2.0	282	940	989.40	1837.47	4048.87
	Cu./ Ft.	0.54	4.52	4.78	6.01	11.15	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
60 C.C.	Lbs.		15.67	52.22	54.97	102.08	224.94
	Cu./ Ft.	0.03	0.25	0.27	0.33	0.62	1.5

Table-87 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	Rheomac 716
Brand	Saudi	Brand	Master Builders
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No.8	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	27
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.49	1.39	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
18	Absolute volume	0.30	10	0.35	282		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
8640 C.C.	Lbs	2.0	282	940	989.40	1837.47	4048.87
	Cu./Ft.	0.54	4.52	4.78	6.01	11.15	27

BATCHES QUANTITIES PER 1. 5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
480 C.C.	Lbs.		15.67	52.22	54.97	102.08	224.94
	Cu./Ft.	0.03	0.25	0.27	0.33	0.62	1.5

Table-88 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Crushed Gravel
Source	Half-Moon, Quarry No.13	Source	Quarry No. 8

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No.8	2.64		0.20	2.7
Coarse Aggregate	$\frac{3}{8}$ in	2.64	91.48	1.31	

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
19	Absolute Volume	0.3	10	0.35	282		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	282	940	989.40	1837.47	4048.87
	Cu./ Ft.	0.54	4.52	4.78	6.01	11.15	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		15.67	52.22	54.97	102.08	224.94
	Cu./ Ft.	0.03	0.25	0.27	0.33	0.62	1.5

Table-89 CONCRETE MIX DESIGN DATA

Portland Cement		Admixture	
Type	V	Type	
Brand	Saudi	Brand	
Fine Aggregate		**Coarse Aggregate**	
Type	Natural Sand	Type	Natural Gravel
Source	Half-Moon, Quarry No.13	Source	Riyadh Area

Material	Max. Size	Specific Gravity S.S.D	Unit Weight lb/cu.ft.	Absorption %	Fineness Modulus
Fine Aggregate	No. 8	2.64		0.2	2.7
Coarse Aggregate	3/8 in	-	-		

MIX COMPUTATION

Mix No	Method	W/C Ratio	Cement Factor	Sand/ Agg.	Water lb/cu.yd.	Slump in	Design Strength Psi
20	Absolute Volume	0.35	10	0.35	329		

ESTIMATED QUANTITIES PER CU. YD. OF CONCRETE

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs	2.0	329	940	946. 16	1757.16	3972.32
	Cu./ Ft.	0.54	5.27	4.78	5.74	10.67	27

BATCHES QUANTITIES PER 1.5 CUBIC FEET

Admixture		Air %	Water	Cement	F. Agg.	C. Agg.	Total
	Lbs.		18.28	52.22	52.56	97.62	220.68
	Cu./ Ft.	0.03	0.29	.27	.32	.59	1.5

Table-90

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
1	V, Saudi	Half-Moon, Quarry No. 13	Quarry No. 7

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Admixture
3/4 in	4 in	8.38	0.4	-

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
1-A	13.5.78	19.5.78	7	6 x 12	28.26	28.72	146.34	103,000	3645
1-B	12.5.78	19.5.78	7	6 x 12	28.26	28.69	146.19	105,000	3716
1-C	12.5.78	19.5.78	7	6 x 12	28.26	28.51	145.27	102,500	3627
Average									3663
1-D	12.5.78	9.6.78	28	6 x 12	28.26	28.68	146.14	135,000	4777
1-E	12.5.78	9.6.78	28	6 x 12	28.26	28.49	145.17	135,000	4777
1-F	12.5.78	9.6.78	28	6 x 12	28.26	28.66	146.04	142,000	5025
Average									4860

Table-91

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
2	V, Saudi	Half-Moon, Quarry No. 13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Admixture
3/4 in	4 in.	8.38	0.4	

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
2-A	12.5.78	19.5.78	7	6 x 12	28.26	29.70	151.34	129,000	4565
2-B	12.5.78	19.5.78	7	6 x 12	28.26	29.31	149.35	131,000	4636
2-C	12.5.78	19.5.78	7	6 x 12	28.26	29.28	149.20	131,000	4636
Average									4612
2-D	12.5.78	9.6.78	28	6 x 12	28.26	29.39	149.76	149,000	5273
2-E	12.5.78	9.6.78	28	6 x 12	28.26	29.42	149.91	164,000	5803
2-F	12.5.78	9.6.78	28	6 x 12	28.26	29.45	150.06	175,000	6193
Average									5756

Table-92 COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
3	V, Saudi	Half-Moon, Quarry No. 13	Quarry No. 11

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Admixture
3/4 in	4 in	8.38	0.4	-

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
2-A	12.5.78	19.5.78	7	6 x 12	28.26	29.07	148.13	122,000	4317
2-B	12.5.78	19.5.78	7	6 x 12	28.26	29.23	148.94	117,000	4140
2-C	12.5.78	19.5.78	7	6 x 12	28.26	29.15	148.54	115,000	4069
Average									4175
2-D	12.5.78	9.6.78	28	6 x 12	28.26	29.09	148.23	169.000	5980
2-E	12.5.78	9.6.78	28	6 x 12	28.26	29.04	147.98	152,000	5379
2-F	12.5.78	9.6.78	28	6 x 12	28.26	29.15	148.54	159,000	5626
Average									5662

Table-93

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
4	V, Saudi	Half-Moon, Quarry No. 13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Admixture
1/2 in	10 in	8.91	0.4	-

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
4-A	26.5.78	2.6.78	7	6 x 12	28.26	29.32	149.40	116,000	4105
4-B	26.5.78	2.6.78	7	6 x 12	28.26	28.98	147.67	119,000	4211
4-C	26.5.78	2.6.78	7	6 x 12	28.16	28.92	147.36	117,000	4140
Average									4152
4-D	26.5.78	23.6.78	28	6 x 12	28.26	28.90	147.26	160,500	5679
4-E	26.5.78	23.6 78	28	6 x 12	28.26	28.88	147.16	179,000	6334
4-F	26.5.78	23.6.78	28	6 x 12	28.26	29.01	147.82	176,000	6228
Average									6080

Table-94

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO 5	CEMENT TYPE, BRAND V, Saudi	FINE AGGREGATE SOURCE Half-Moon, Quarry No. 13	COURSE AGGREGATE SOURCE Quarry No. 8	
Max. Size of Aggregate 3/8	Slump 10 in	Cement (SK/cu. yd.) 9.31	W/c Ratio .4	Admixture -

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
5-A	26.5.78	2.6.78	7	6 x 12	28.26	28.54	145.43	123,500	4370
5-B	26.5.78	2.6.78	7	6 x 12	28.26	28.59	145.68	120,000	4246
5-C	26.5.78	2.6.78	7	6 x 12	28.26	28.65	145.99	121,500	4299
Average									4305
5-D	26.5.78	23.6.78	28	6 x 12	28.26	28.41	144.76	171,500	6069
5-E	26.5.78	23.6.78	28	6 x 12	28.26	28.45	144.97	172,000	6086
5-F	26.5.78	23.6.78	28	6 x 12	28.26	28.46	145.02	182,000	6440
Average									6198

Table-95

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
6	V SAUDI	Half-Moon Quarry No. 13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/4	3 in.	8	.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density ($lb/ft.^3$)	Load (lbs)	Compressive Strength (Psi)
6-A	4/6/1978	7/6/78	3	6 x 12	28.26	29.63	150.98	110,000	3892
6-B	4/6/1978	11/6/78	7	6 x 12	28.26	29.63	150.98	140,000	4954
6-C	4/6/1978	11/6/78	7	6 x 12	28.26	29.77	151.69	126,500	4476
6-D	4/6/1978	11/6/78	7	6 x 12	28.26	29.74	151.54	139,500	4936
Average									4789
6-E	4/6/1978	2/7/78	28	6 x 12	28.26	30.04	153.07	174,500	6175
6-F	4/6/1978	2/7/78	28	6 x 12	28.26	29.63	150.98	200,000	7077
6-G	4/6/1978	2/7/78	28	6 x 12	28.26	29.58	150.73	173,000	6122
Average									6458

Table-96

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
7	V, SAUDI	Half-Moon, Quarry No. 13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
½	3 in.	8	.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density ($lb/ft.^3$)	Load (lbs)	Compressive Strength (Psi)
7-A	4/6/78	7/6/78	3	6 x 12	28.26	29.46	150.12	108,500	3839
7-B	4/6/78	11/6/78	7	6 x 12	28.26	29.58	150.73	131,000	4636
7-C	4/6/78	11/6/78	7	6 x 12	28.26	29.59	150.78	133,000	4706
7-D	4/6/78	11/6/78	7	6 x 12	28.26	29.48	150.22	125,500	4441
Average									4594
7-E	4/6/78	2/7/78	28	6 x 12	28.26	29.66	151.13	205,000	7254
7-F	4/6/78	2/7/78	28	6 x 12	28.26	29.77	151.69	187,000	6617
7-G	4/6/78	2/7/78	28	6 x 12	28.26	29.58	150.73	173,000	6122
Average									6664

Table-97

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO 8	CEMENT TYPE, BRAND V, SAUDI	FINE AGGREGATE SOURCE Half-Moon, Quarry No.13	COURSE AGGREGATE SOURCE Quarry No. 8	
Max. Size of Aggregate 3/8 (in)	Slump 1.5 in	Cement (SK/cu. yd.) 8	W/c Ratio .35	Sand/Aggregate 0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
8-A	4/6/78	7/6/78	3	6 x 12	28.26	29.36	149.61	116,500	4122
8-B	4/6/78	11/6/78	7	6 x 12	28.26	29.58	150.73	137,000	4848
8-C	4/6/78	11/6/78	7	6 x 12	28.26	29.58	150.73	148,000	5237
8-D	4/6/78	11/6/78	7	6 x 12	28.26	29.52	150.42	143,000	5060
Average									5048
8-E	4/6/78	2/7/78	28	6 x 12	28.26	29.44	150.01	220,300	7796
8-F	4/6/78	2/7/78	28	6 x 12	28.26	29.4	149.81	200,950	7323
8-G	4/6/78	2/7/78	28	6 x 12	28.26	29.5	150.32	215,900	7640
Average									7586

Table-98

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
9	V, SAUDI	Half-Moon, Quarry No.13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/8	0.5 in	7	.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
9-A	8/6/78	11/6/78	3	6x12	28.26	29.59	150.78	122,000	4317
9-B	8/6/78	15/6/78	7	6x12	28.26	29.55	150.57	155,000	5485
9-C	8/6/78	15/6/78	7	6x12	28.26	29.46	150.12	154,500	5449
9-D	8/6/78	15/6/78	7	6x12	28.26	29.68	151.24	152,500	5396
Average									5443
9-E	8/6/78	5/7/78	28	6x12	28.26	29.57	150.68	210,350	7443
9-F	8/6/78	5/7/78	28	6x12	28.26	29.45	150.06	201,500	7130
9-G	8/6/78	5/7/78	28	6x12	28.26	29.4	149.81	192,700	6819
Average									7131

Table-99

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
10	V, SAUDI	Half-Moon, Quarry No.13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/8 in.	3 in.	9	.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
10-A	8/6/78	11/6/78	3	6x12	28.26	29.24	148.99	112,000	3963
10-B	8/6/78	15/6/78	7	6x12	28.26	29.23	148.94	151,000	5343
10-C	8/6/78	15/6/78	7	6x12	28.26	29.25	149.05	149,000	5273
10-D	8/6/78	15/678	7	6x12	28.26	29.27	149.15	145,000	5131
Average									5249
10-E	8/6/78	5/7/78	28	6x12	28.26	29.28	149.20	204,850	7249
10-F	8/6/78	5/7/78	28	6x12	28.26	29.23	148.94	211,450	7482
10-G	8/6/78	5/7/78	28	6x12	28.26	29.39	149.76	214,800	7601
Average									7444

Table-100

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
11	V, SAUDI	Half-Moon, Quarry No.13	Quarry No.8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/8	6 in.	10	0.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
11-A	8/6/78	11/6/78	3	6x12	28.26	29.02	147.87	126,000	4459
11-B	8/6/78	15/6/78	7	6x12	28.26	29.01	147.82	157,000	5556
11-C	8/6/78	15/6/78	7	6x12	28.26	29.45	150.06	155,500	5503
11-D	8/6/78	15/6/78	7	6x12	28.26	29.03	147.92	159,000	5626
Average									5562
11-E	8/6/78	5/7/78	28	6x12	28.26	29.34	149.50	252,203	8924
11-F	8/6/78	5/7/78	28	6x12	28.26	28.95	147.52	182,819	6469
11-G	8/6/78	5/7/78	28	6x12	28.26	29.12	148.38	258,811	9158
Average									8183

Table-101

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO 12	CEMENT TYPE, BRAND V,SAUDI	FINE AGGREGATE SOURCE Half-Moon, Quarry No.13	COURSE AGGREGATE SOURCE Quarry No. 8	
Max. Size of Aggregate 3/8 in.	Slump 1.25 in	Cement (SK/cu. yd.) 10	W/c Ratio .35	Sand/Aggregate 0.3

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
12-A	11/6/78	14/6/78	3	6x12	28.26	28.65	145.99	99,000	3503
12-B	11/6/78	18/6/78	7	6x12	28.26	28.55	145.48	126,000	4459
12-C	11/6/78	18/6/78	7	6x12	28.26	28.80	146.75	127,000	4494
12-D	11/6/78	11/6/78	7	6x12	28.26	28.63	145.89	122,000	4317
Average									4423
12-E	11/6/78	9/7/78	28	6x12	28.26	28.73	146.40	196,500	6937
12-F	11/6/78	9/7/78	28	6x12	28.26	28.94	147.50	193,800	6858
12-G	11/6/78	9/7/78	28	6x12	28.26	28.76	146.55	191,600	6780
Average									6858

Table-102 COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
13	V, SAUDI	Half-Moon, Quarry No.13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/8	4.5 in.	10	.35	0.4

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
13-A	11/6/78	14/6/78	3	6x12	28.26	28.69	146.19	89,000	3149
13-B	11/6/78	18/6/78	7	6x12	28.26	28.66	146.04	115,000	4069
13-C	11/6/78	18/6/78	7	6x12	28.26	28.54	145.43	116,000	4105
13-D	11/6/78	18/6/78	7	6x12	28.26	28.49	145.17	116,000	4105
Average									4093
13-E	11/6/78	9/7/78	28	6x12	28.26	28.43	144.87	181,700	6430
13-F	11/6/78	9/7/78	28	6x12	28.26	28.58	145.63	177,300	6274
13-G	11/6/78	9/7/78	28	6x12	28.26	28.53	145.38	176,200	6235
Average									6313

Table-103

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
14	I, Japanese	Half-Moon, Quarry No.13	Quarry No.8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Admixture
3/8 in.	0.75 in	10	0.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
14-A	14/6/78	17/6/78	3	6x12	28.26	28.45	144.97	116,000	4105
14-B	14/6/78	21/6/78	7	6x12	28.26	28.31	144.26	125,000	4423
14-C	14/6/78	21/6/78	7	6x12	28.26	28.63	145.89	128,000	4529
14-D	14/6/78	21/6/78	7	6x12	28.26	28.51	145.27	130,500	4618
Average									4523
14-E	14/6/78	14/7/78	28	6x12	28.26	28.75	146.50	165,200	5846
14-F	14/6/78	14/7/78	28	6x12	28.26	28.55	145.48	160,800	5690
14-G	14/6/78	14/7/78	28	6x12	28.26	28.57	145.58	169,600	6001
Average									5846

Table-104

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE *
15	V, SAUDI	Half-Moon, Quarry No.13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/8 in.	2.5 in.	10	0.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
15-A	14/6/78	17/6/78	3	6x10	28.26	24.03	122.45	54,000	1911
15-B	14/6/78	21/6/78	7	6x12	28.26	28.56	145.53	108,000	3822
15-C	14/6/78	21/6/78	7	6x12	28.26	28.36	144,51	119,000	4211
15-D	14/6/78	21/6/78	7	6x12	28.26	28.52	145.33	106,000	3751
Average									3928
15-E	14/6/78	14/7/78	28	6x12	28.26	28.75	146.50	180,600	6391
15-F	14/6/78	14/7/78	28	6x12	28.26	28.50	148.22	176,200	6235
15-G	14/6/78	14/7/78	28	6x12	28.26	28.45	144.97	172,900	6118
Average									6248

* The coarse aggregate is not washed in this mix.

Table-105 COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
16	V, SAUDI	Half-Moon, Quarry No.13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Admixture : 300 N
3/8	2.0 in	10	0.30	Sand/Agg. = .35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
16-A	14/6/78	17/6/78	3	6x12	28.26	29.00	147.77	131,500	4653
16-B	14/6/78	21/6/78	7	6x12	28.26	28.84	146.96	148,000	5237
16-C	14/6/78	21/6/78	7	6x12	28.26	28.53	145.38	162,000	5733
16-D	14/6/78	21/6/78	7	6x12	28.26	28.68	146.14	151,000	5343
Average									5438
16-E	14/6/78	14/7/78	28	6x12	28.26	28.78	146.65	212,600	7523
16-F	14/6/78	14/7/78	28	6x12	28.26	28.95	147.52	223,600	7912
16-G	14/6/78	14/7/78	28	6x12	28.26	28.75	146.50	229,100	8107
Average									7847

Table-106

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
17	V, SAUDI	Half-Moon, Quarry No.13	Quarry No. 8

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Admixture 748 ME
3/8 in.	0.75 in	10	0.3	Sand/Agg. = 0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
17-A	16/6/1978	19/6/78	3	6x12	28.26	28.98	147.67	142,000	5025
17-B	16/6/78	16/6/78	7	6x12	28.26	29.03	147.92	174,500	6175
17-C	16/6/78	21/6/78	7	6x12	28.26	28.94	147.47	165,500	5856
17-D	16/6/78	21/6/78	7	6x12	28.26	28.97	147.62	171,500	6069
Average									6033
17-E	16/6/1978	14/7/78	28	6x12	28.26	29.07	148.[illegible]3	239,000	8457
17-F	16/6/78	14/7/78	28	6x12	28.26	29.10	148.28	236,800	8379
17-G	16/6/78	14/7/78	28	6x12	28.26	29.18	148.69	231,300	8185
									8340
Average									8340

Table-107

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO 18	CEMENT TYPE, BRAND V, SAUDI	FINE AGGREGATE SOURCE Half-Moon, Quarry No. 13	COURSE AGGREGATE SOURCE Quarry No. 8	
Max. Size of Aggregate 3/8 in.	Slump 11 in.	Cement (SK/cu. yd.) 10	W/c Ratio 0.30	Admixture: RHEOMAC 716 Sand/Agg: = 0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
18-A	16/6/78	19/6/78	3	6x12	28.26	29.23	148.94	133,000	4706
18-B	16/6/78	21/6/78	7	6x12	28.26	29.15	148.54	165,500	5856
18-C	16/6/78	21/6/78	7	6x12	28.26	29.25	149.05	162,500	5750
18-D	16/6/78	21/6/78	7	6x12	28.26	29.31	149.35	153,000	5414
Average									5673
19-E	16/6/78	14/7/78	28	6x12	28.26	29.22	148.90	215,900	7640
19-F	16/6/78	14/7/78	28	6x12	28.26	29.16	148.59	202,600	7169
19-G	16/6/78	14/7/78	28	6x12	28.26	29.04	147.98	214,800	7601
Average									7470

Table-108

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO 19	CEMENT TYPE, BRAND V, SAUDI	FINE AGGREGATE SOURCE Half-Moon, Quarry No.13	COURSE AGGREGATE SOURCE Quarry No.8	
Max. Size of Aggregate 3/8 in.	Slump Zero	Cement (SK/cu. yd.) 10	W/c Ratio 0.30	Sand/Aggregate 0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
19-A	16/6/78	19/6/78	3	6x12	28.26	28.91	147.31	100,000	3539
19-B	16/6/78	21/6/78	7	6x12	28.26	28.93	147.41	126,500	4476
19-C	16/6/78	21/6/78	7	6x12	28.26	29.15	148.54	143,000	5060
19-D	16/6/78	21/6/78	7	6x12	28.26	28.89	147.21	128,500	4547
Average									4694
19-E	16/6/78	14/6/78	28	6x12	28.26	29.12	148.38	202,600	7169
19-F	16/6/78	14/7/78	28	6x12	28.26	29.04	148.23	198,200	7014
19-G	16/6/78	14/7/78	28	6x12	28.26	29.55	150.57	200,400	7091
Average									7091

Table-109

COMPRESSIVE STRENGTH OF CONCRETE

MIX NO	CEMENT TYPE, BRAND	FINE AGGREGATE SOURCE	COURSE AGGREGATE SOURCE
20	V, SAUDI	Half-Moon, Quarry No.13	Riyadh, Natural Gravel

Max. Size of Aggregate	Slump	Cement (SK/cu. yd.)	W/c Ratio	Sand/Aggregate
3/8 in.	7 inch	10	.35	0.35

Sample	Date Molded	Date Tested	Age (days)	Dimensions (inches)	Area (sq. in)	Weight (lbs)	Density (lb/ft.^{3})	Load (lbs)	Compressive Strength (Psi)
20-A	26/6/78	29/7/78	3	6x12	28.26	29.11	148.33	96,500	3415
20-B	26/6/78	3/7/78	7	6x12	28.26	29.16	148.59	130,000	4600
20-C	26/6/78	3/7/78	7	6x12	28.26	29.19	148.74	135,500	4795
20-D	26/6/78	3/7/78	7	6x12	28.26	29.16	148.59	132,200	4678
Average									4691
20-E	26/6/78	24/7/78	28	6x12	28.26	29.25	149.05	187,200	6624
20-F	26/6/78	24/7/78	28	6x12	28.26	29.09	148.23	188,300	6664
20-G	26/6/78	24/7/78	28	6x12	28.26	29.07	148.13	188,300	6664
Average									6651

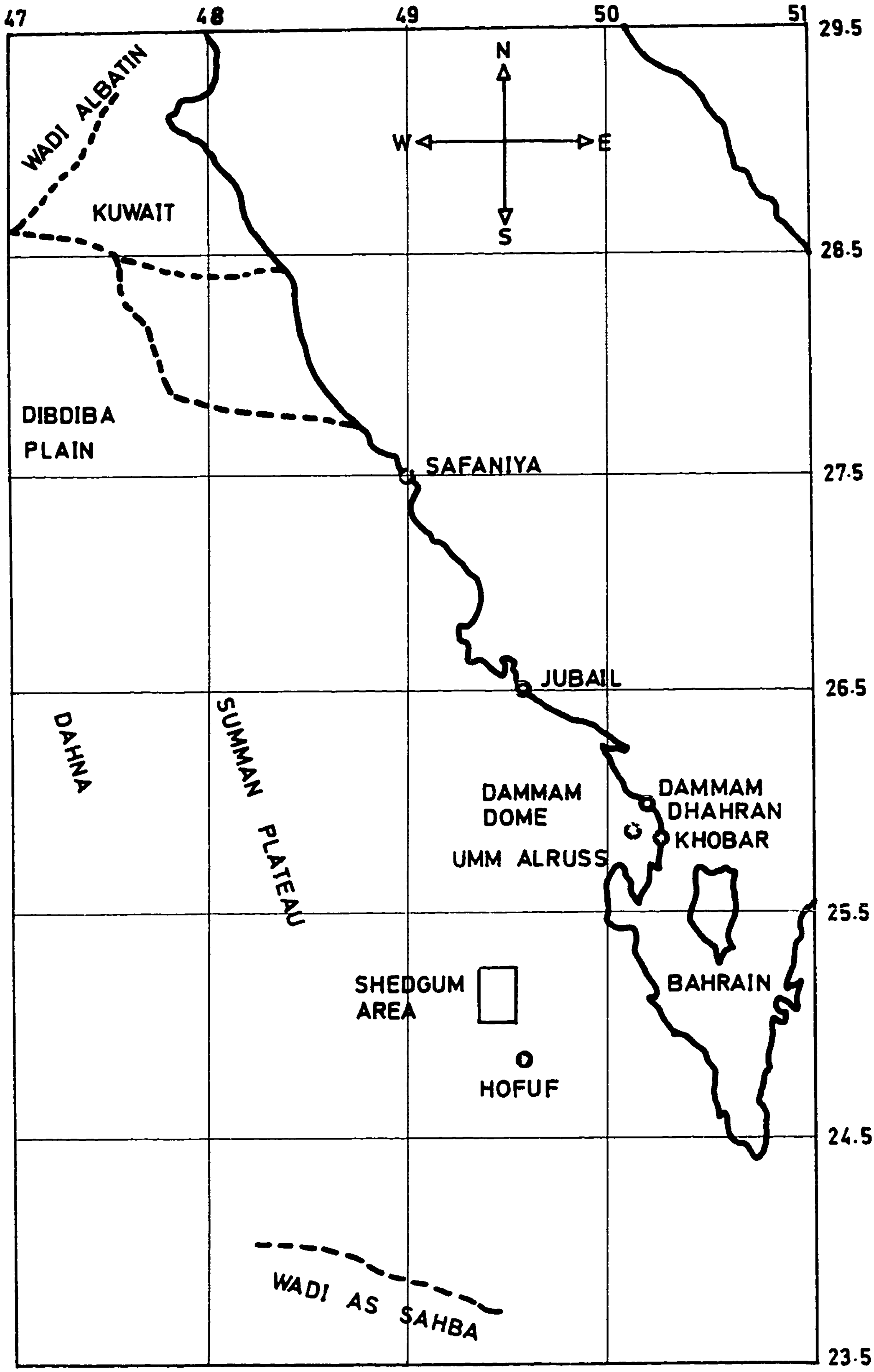

FIG. 1 GEOLOGICAL FORMATION LOCATION

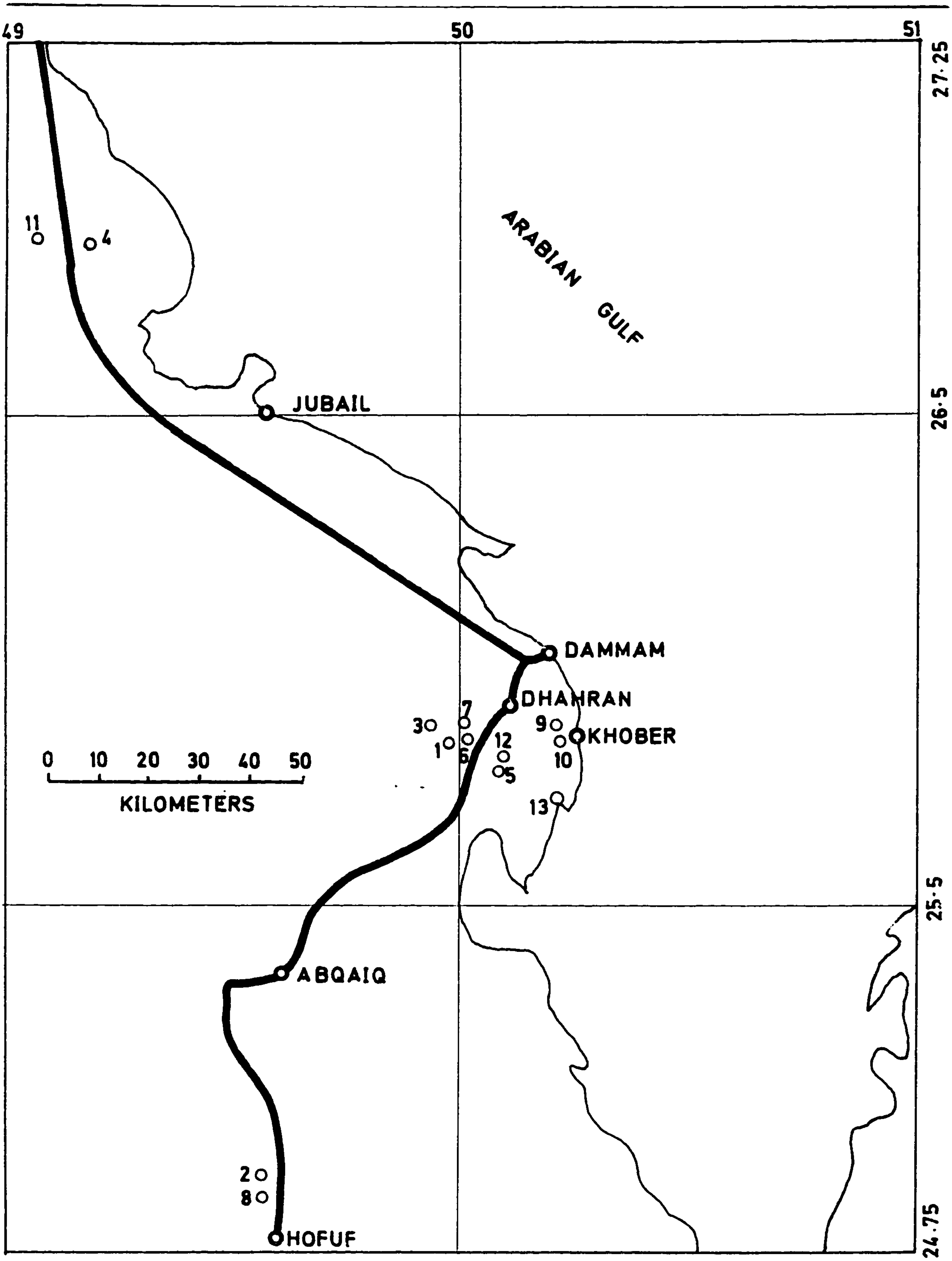

FIG. 2 QUARIES LOCATION

DEMAND AND SUPPLY FOR CRUSHED STONE

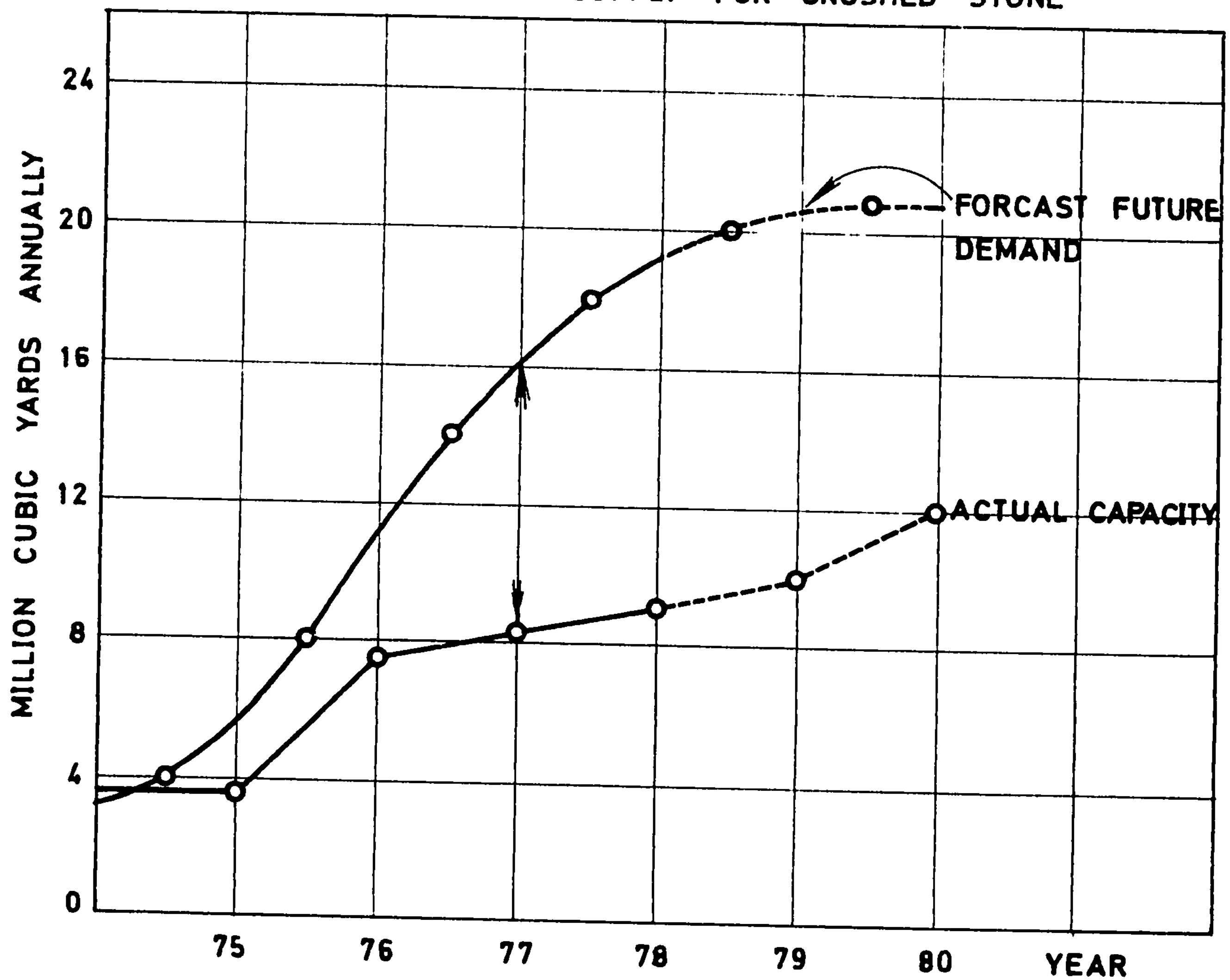

FIG. 3 BASED ON ARAMCO AND SIDF DATA

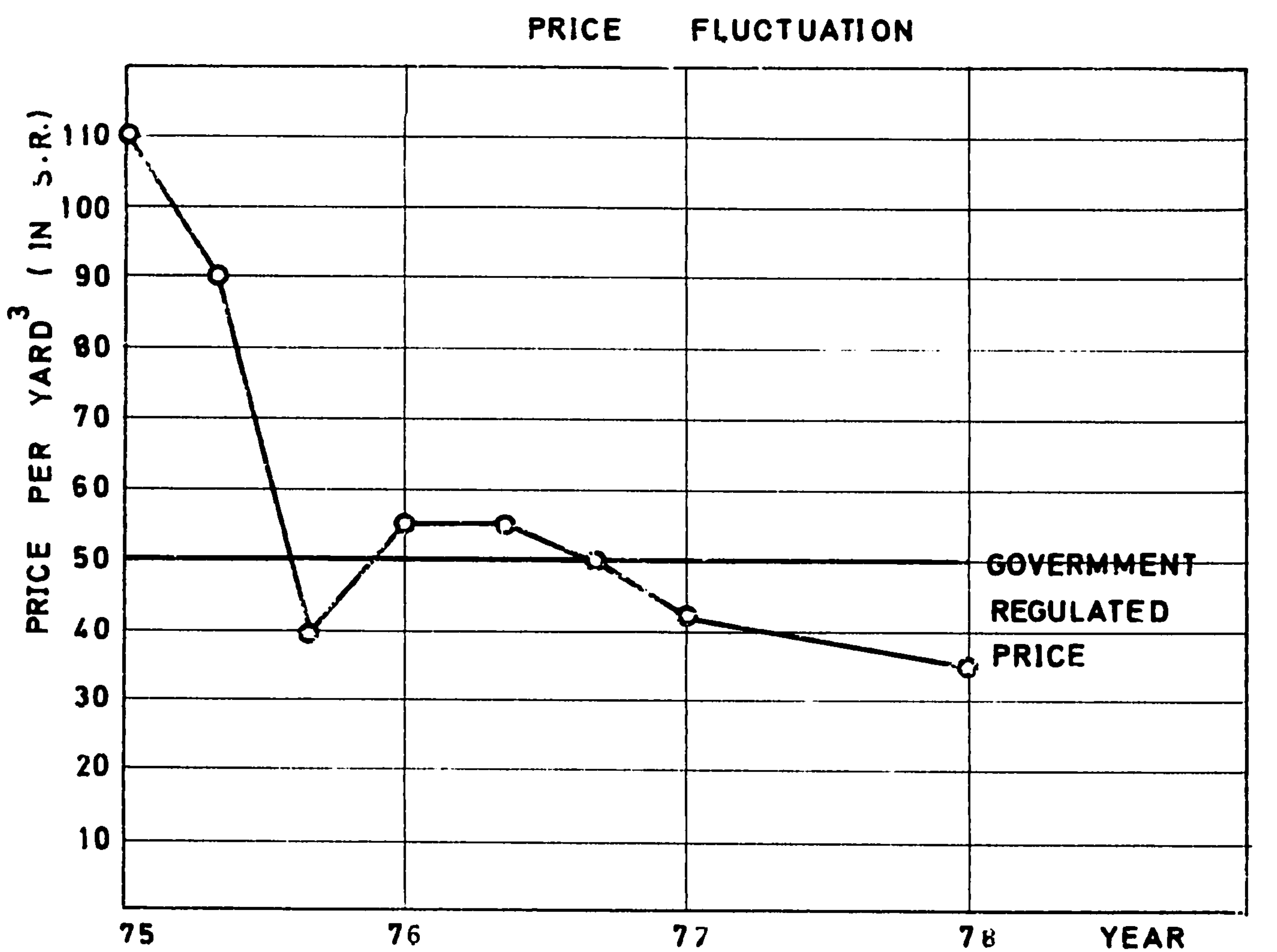

FIG. (4) BASED ON ARAMCO, SIDF, AND STATISTICAL DATA OF THIS PAPER.

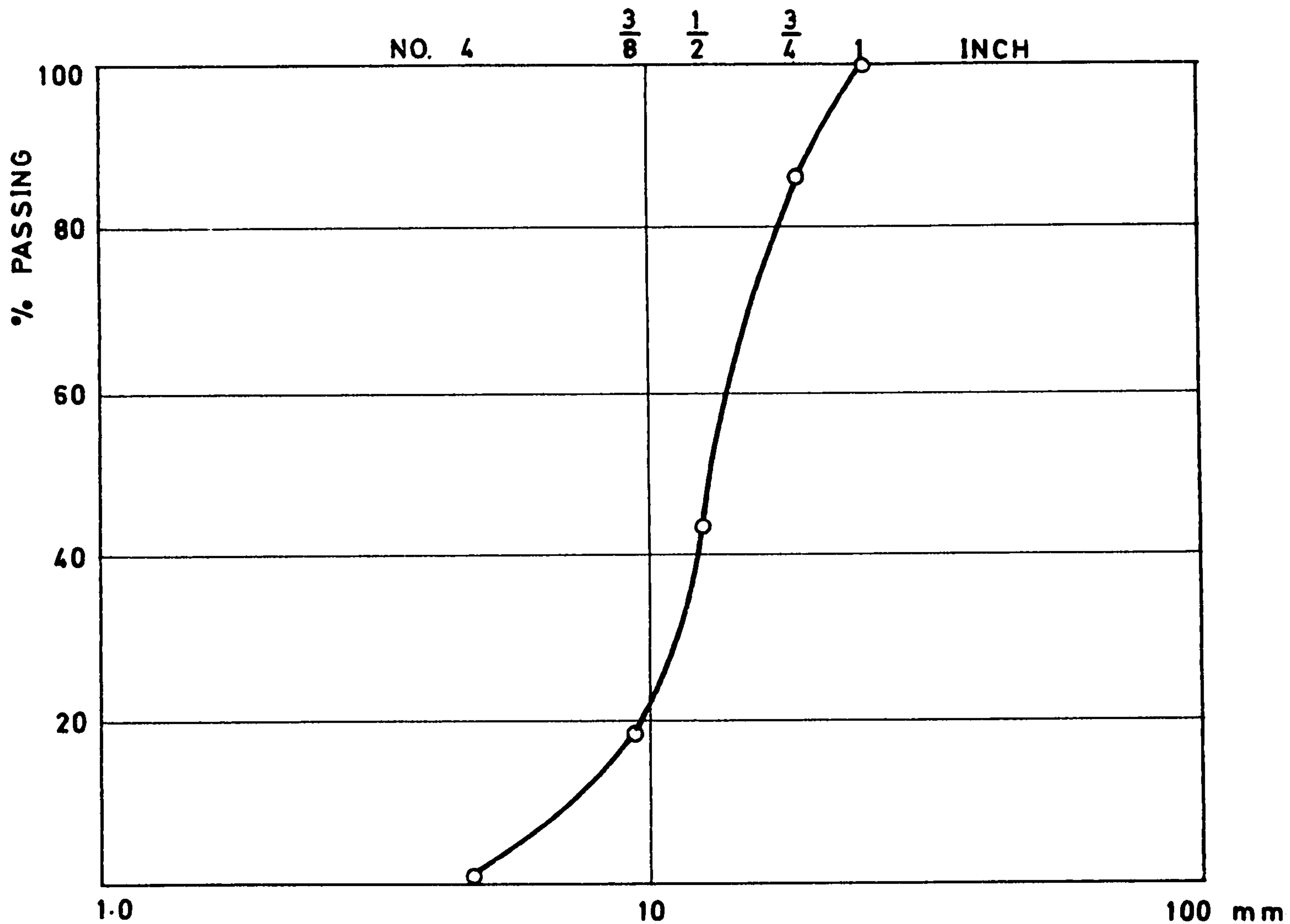

FIG. 5 QUARRY NO. 1 GRADING CURVE

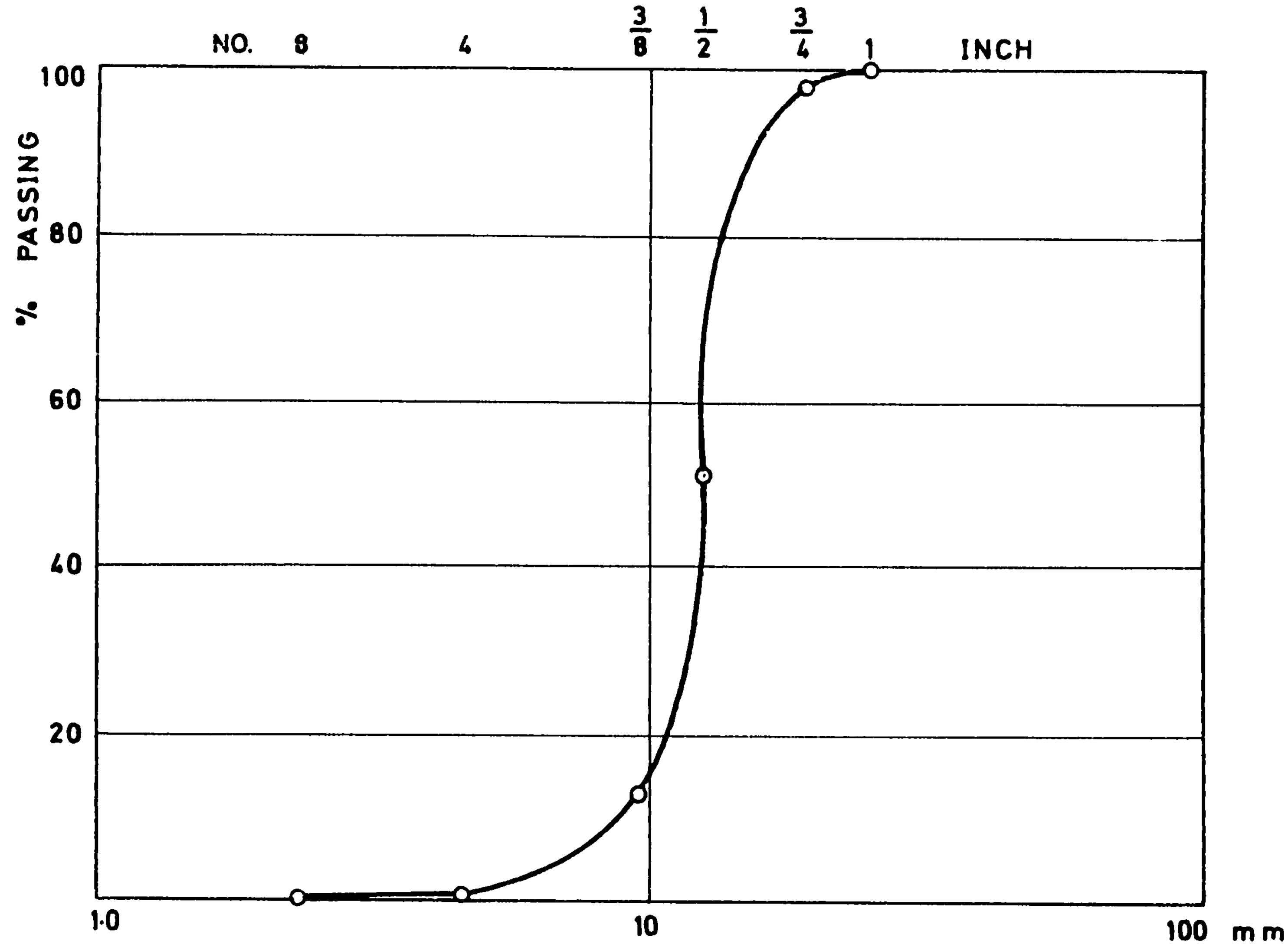

FIG.6 QUARRY NO. 2 GRADING CURVE

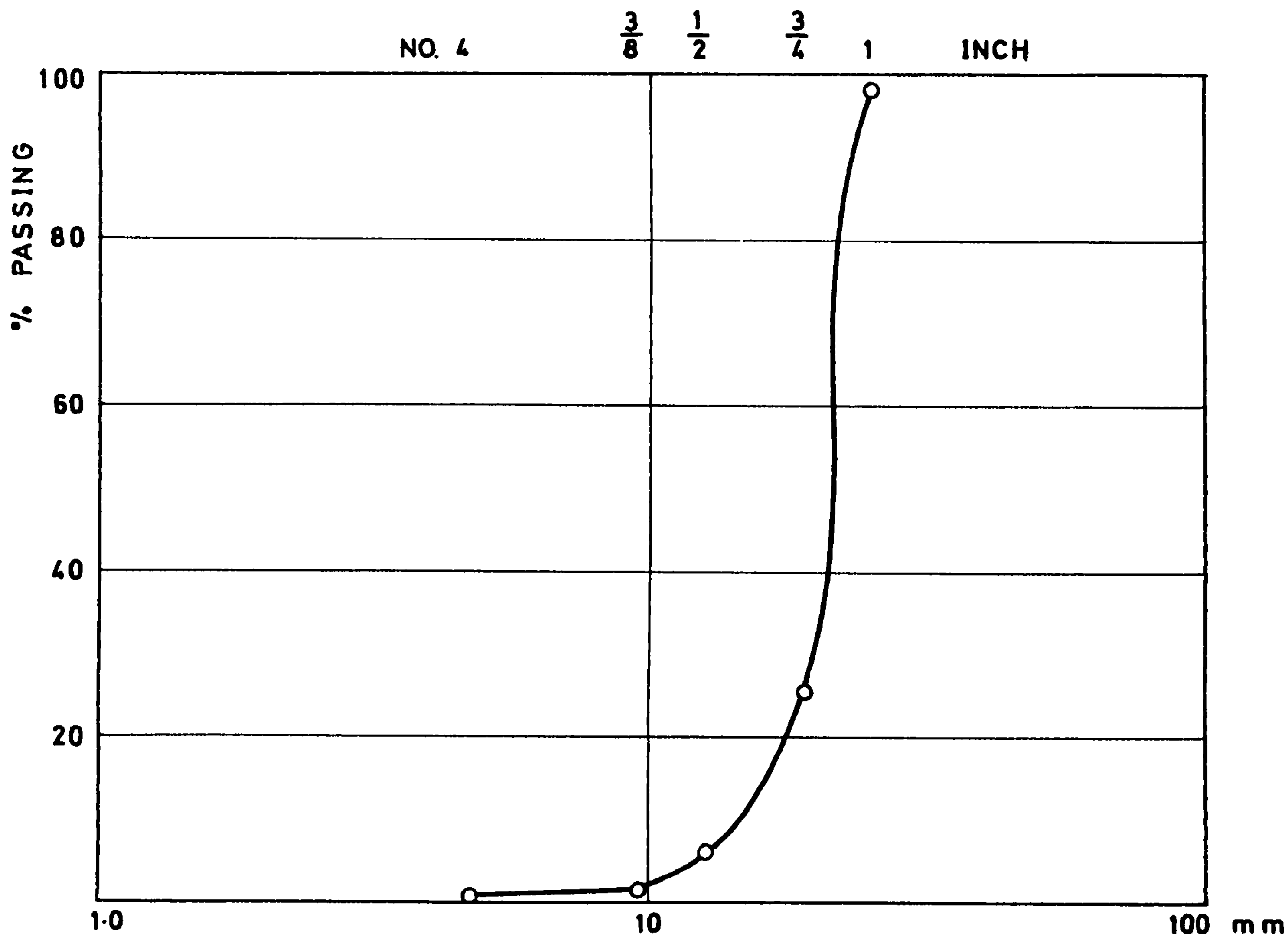

FIG. 7 QUARRY NO. 3 GRADING CURVE

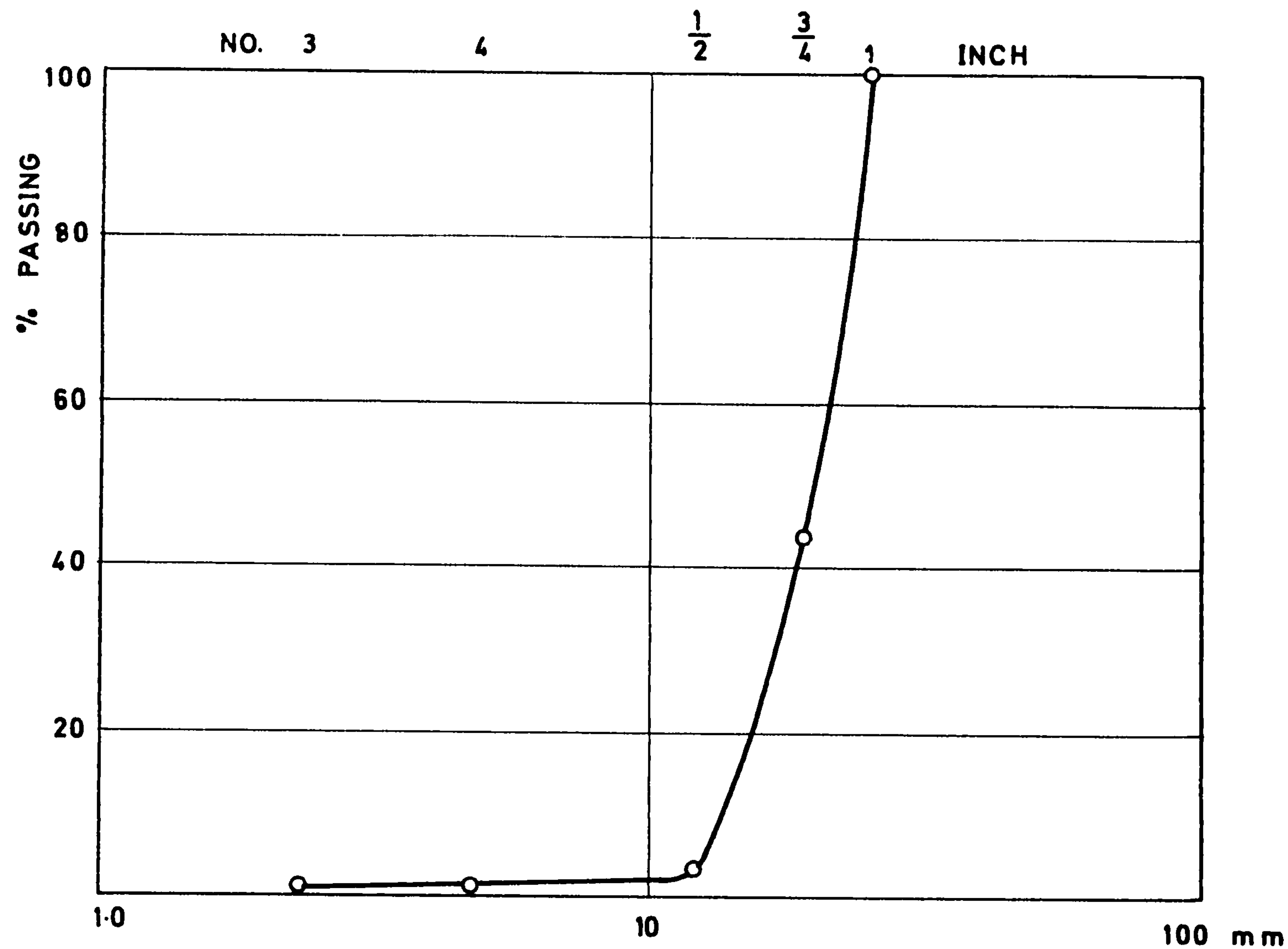

FIG. 8 QUARRY NO. 4 GRADING CURVE

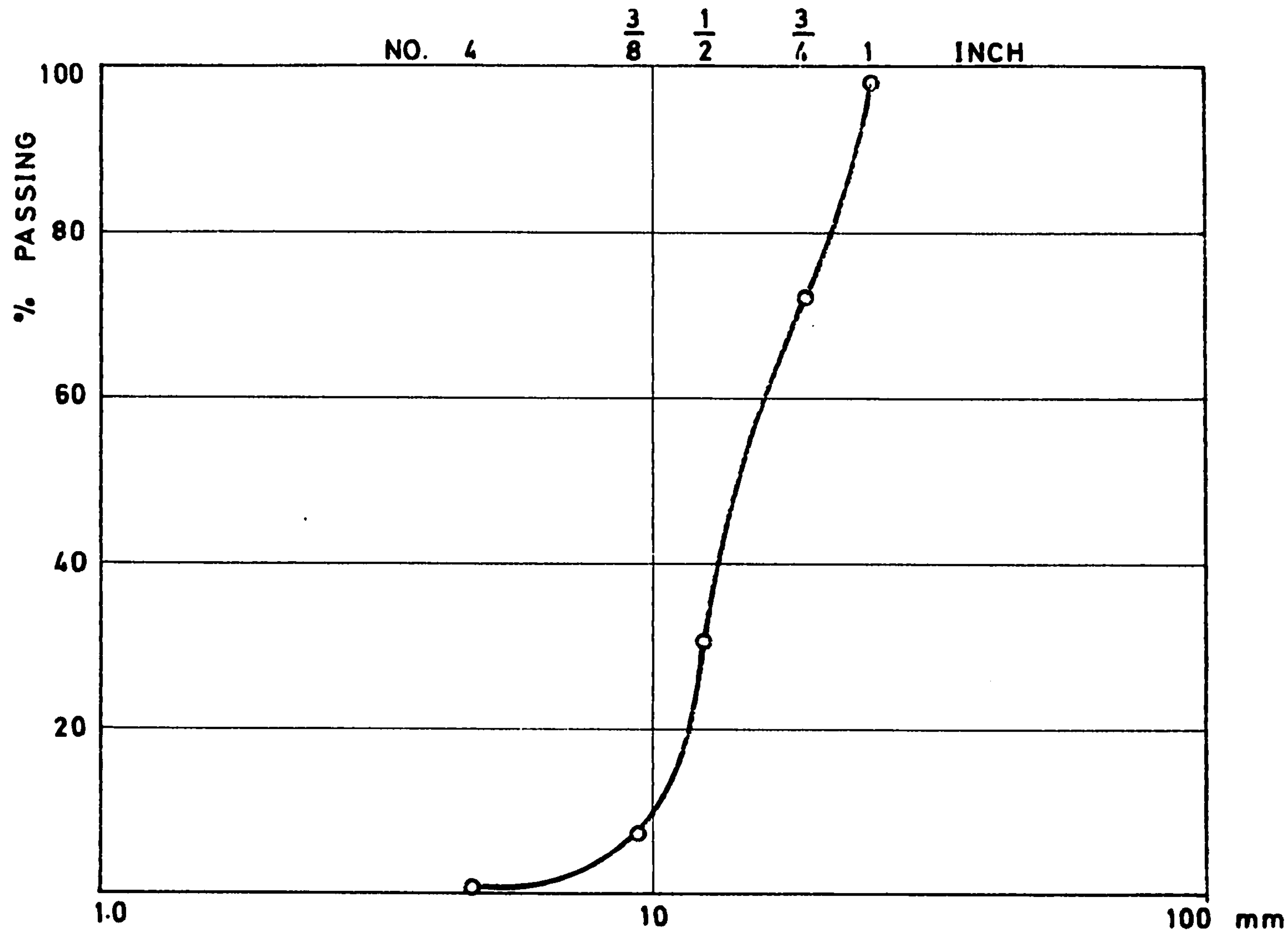

FIG. 9 QUARRY NO. 5 GRADING CURVE

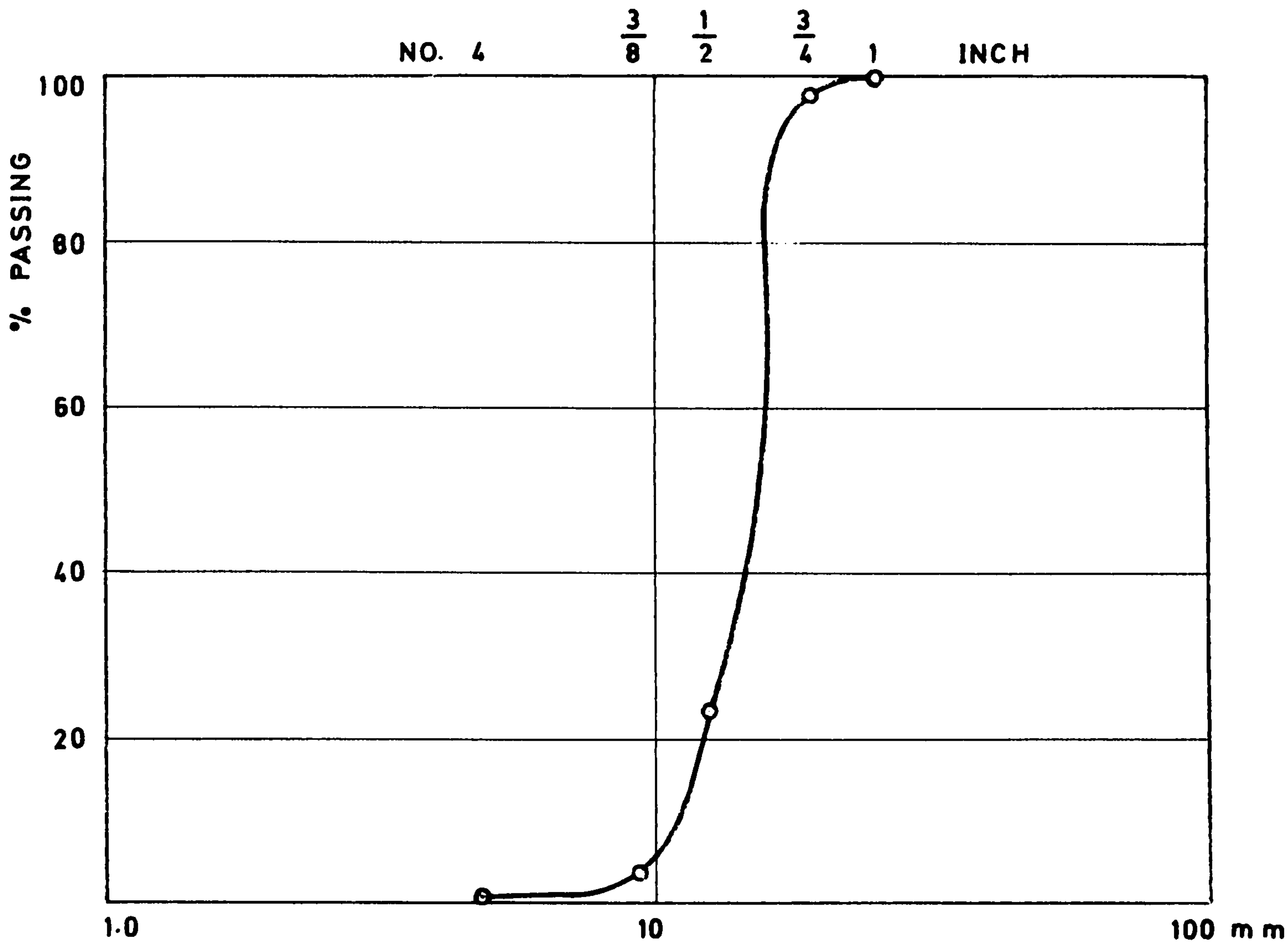

FIG. 10 QUARRY NO. 6 GRADING CURVE

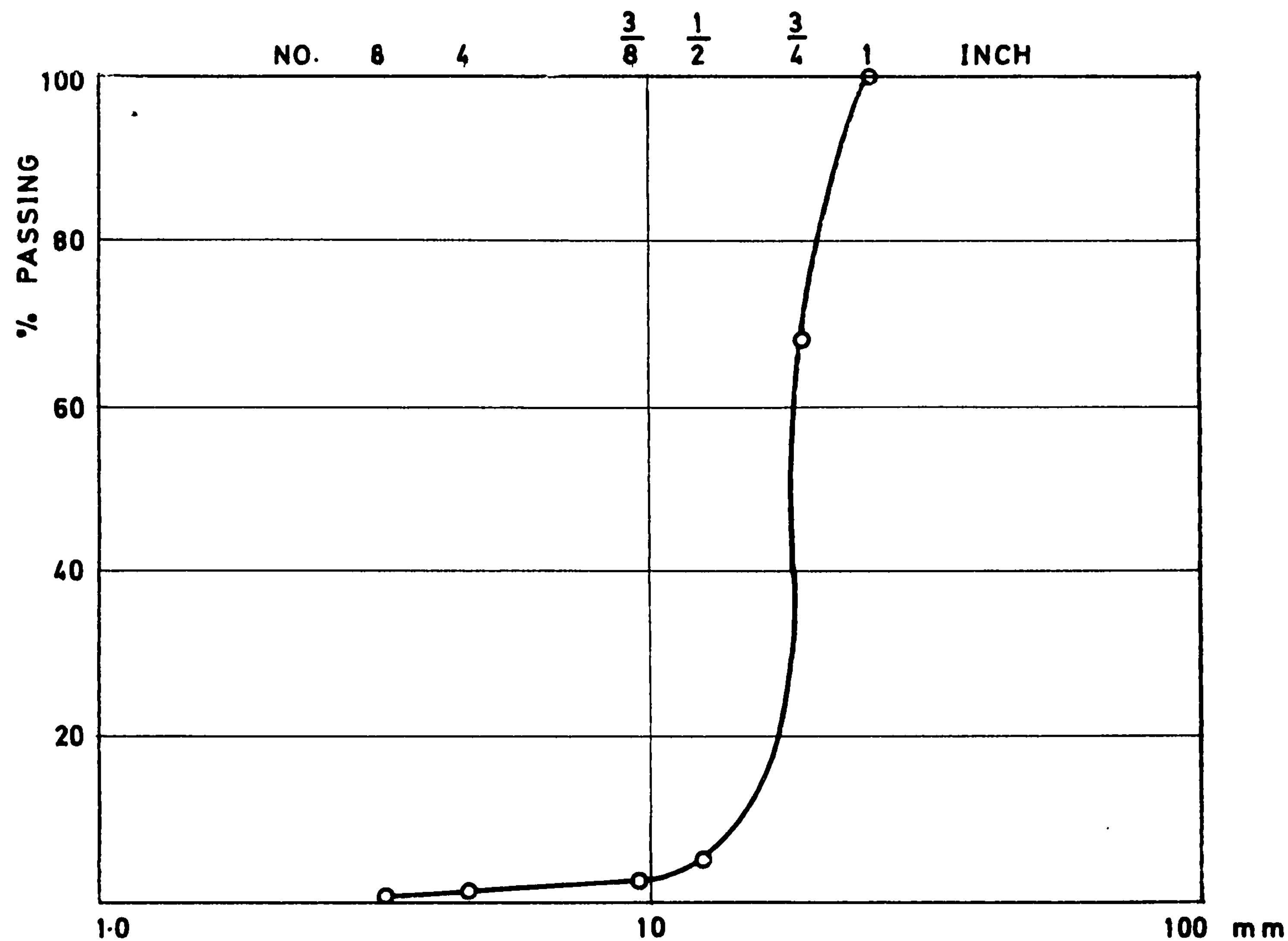

FIG. 11 QUARRY NO. 7 GRADING CURVE

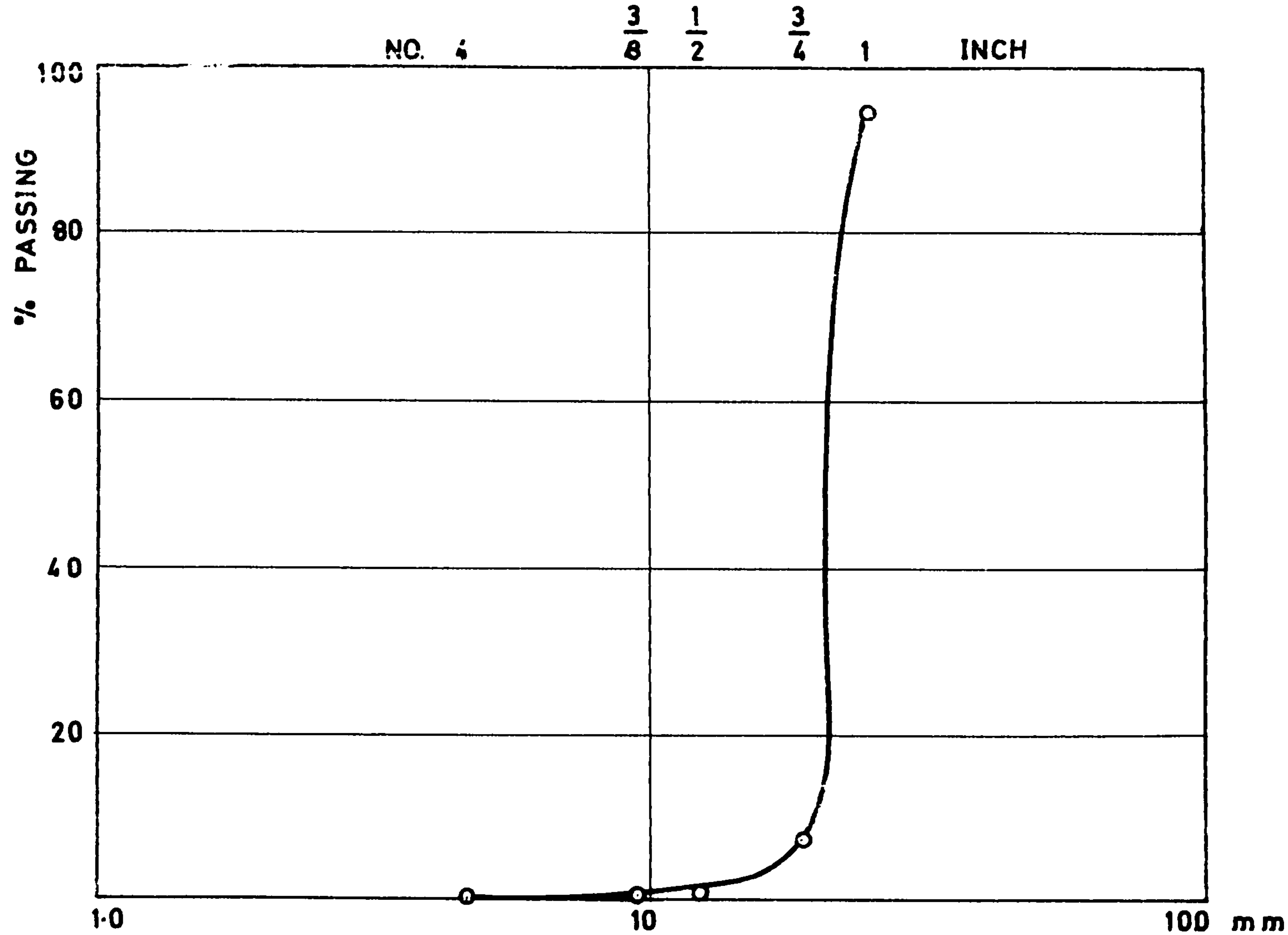

FIG. 12 QUARRY NO. 8 GRADING CURVE

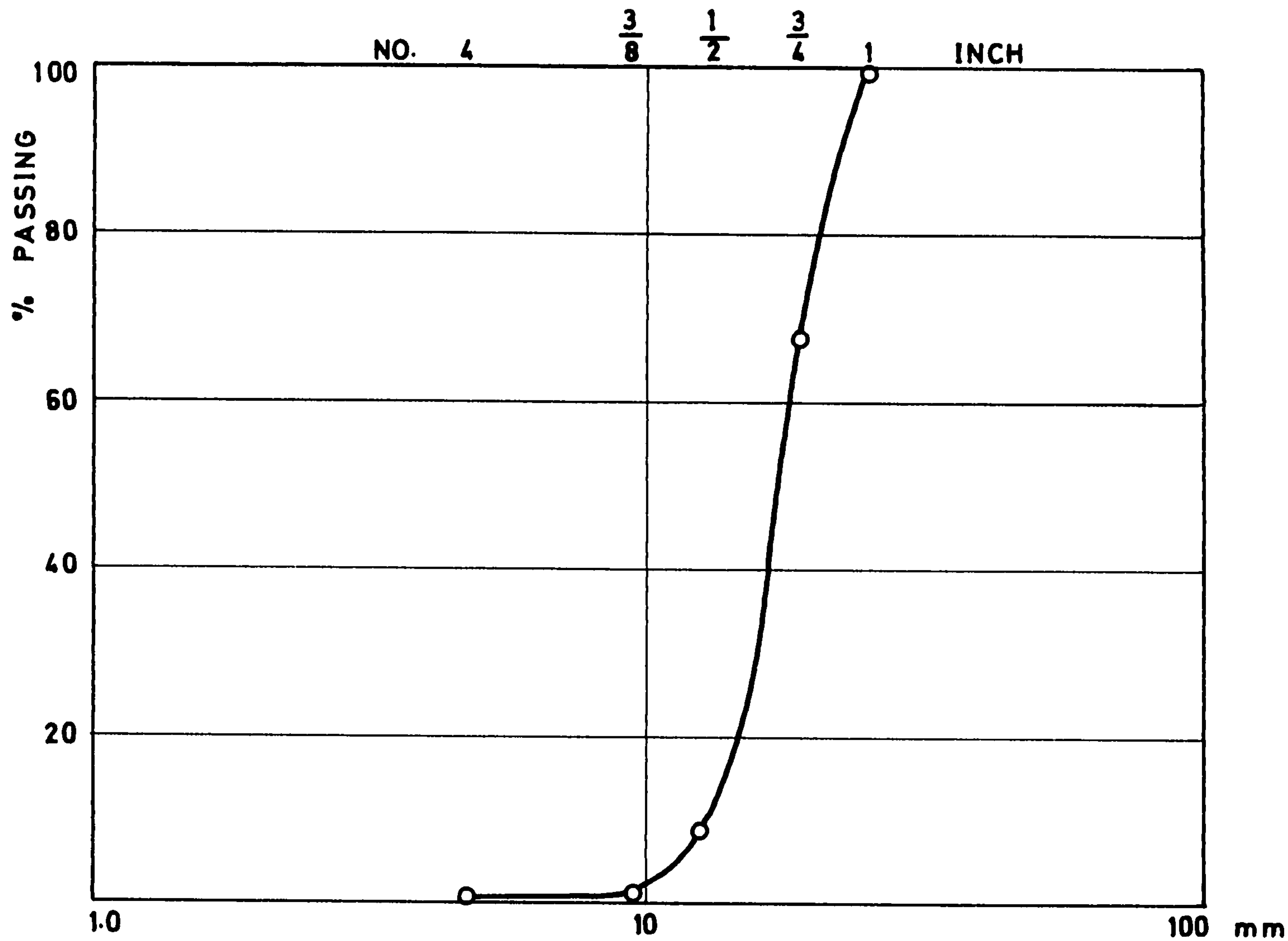

FIG.13 QUARRY NO. 9 GRADING CURVE

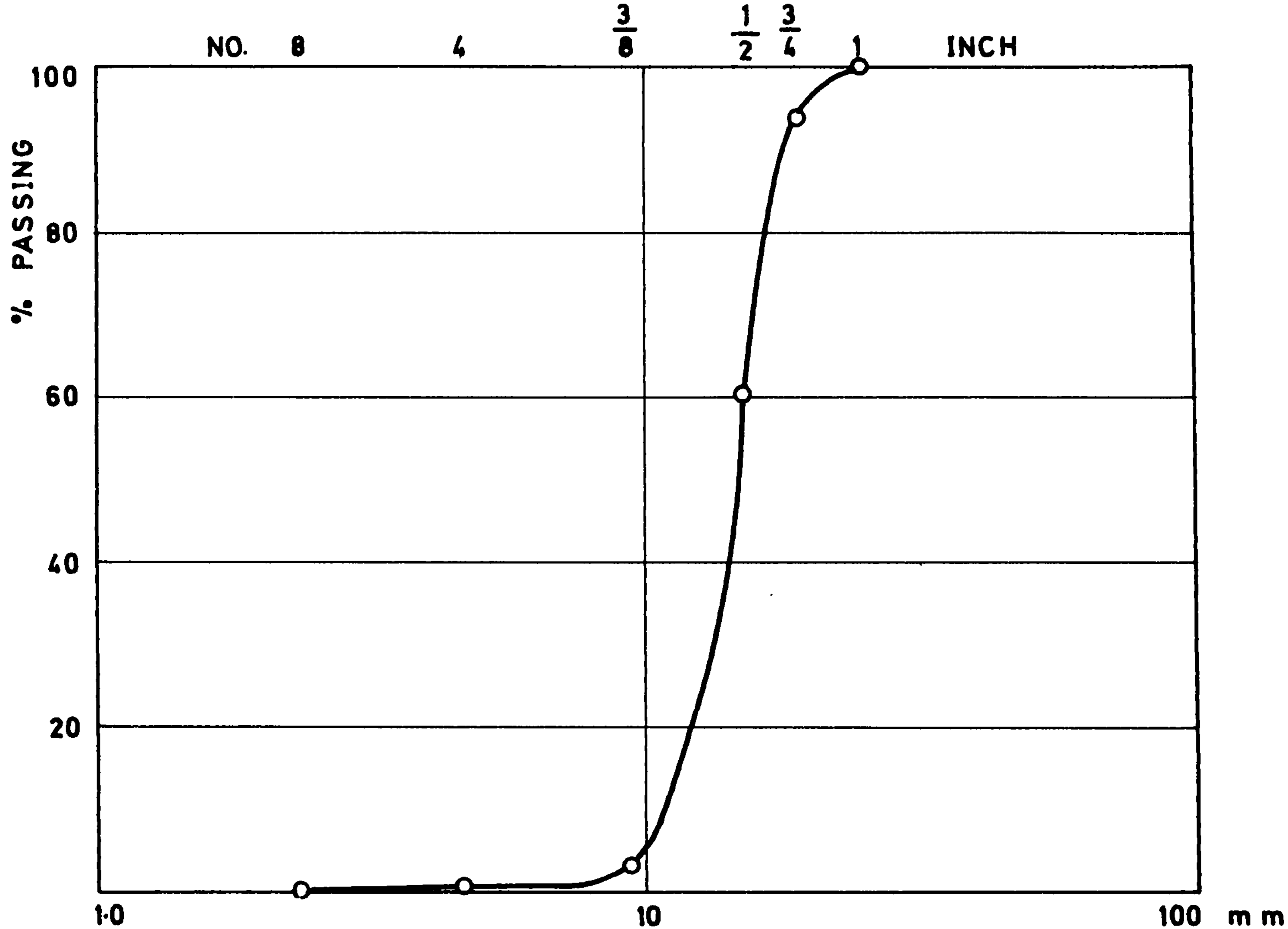

FIG. 14 QUARRY NO. 10 GRADING CURVE

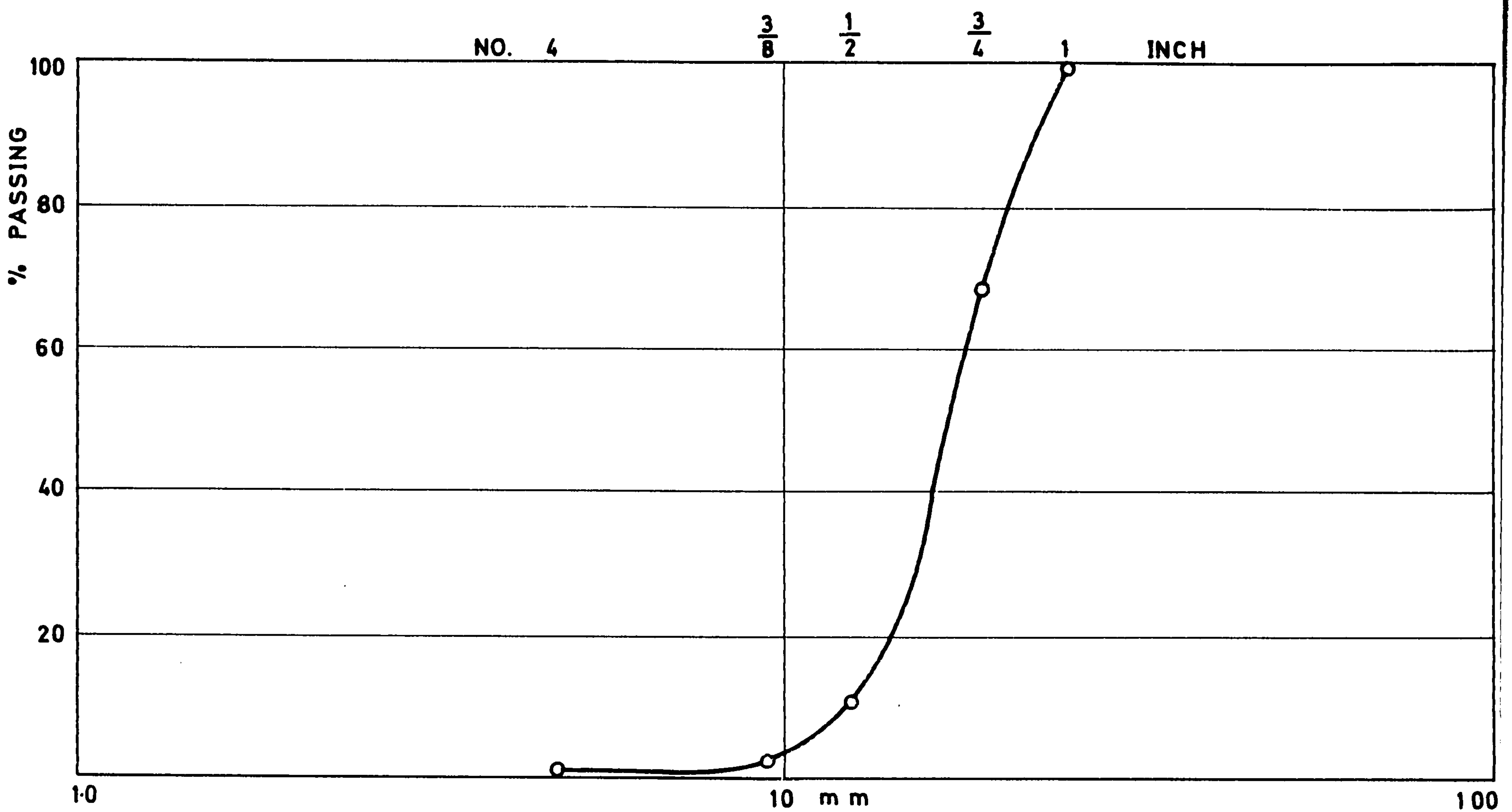

FIG. 15 QUARRY NO. 11 GRADING CURVE

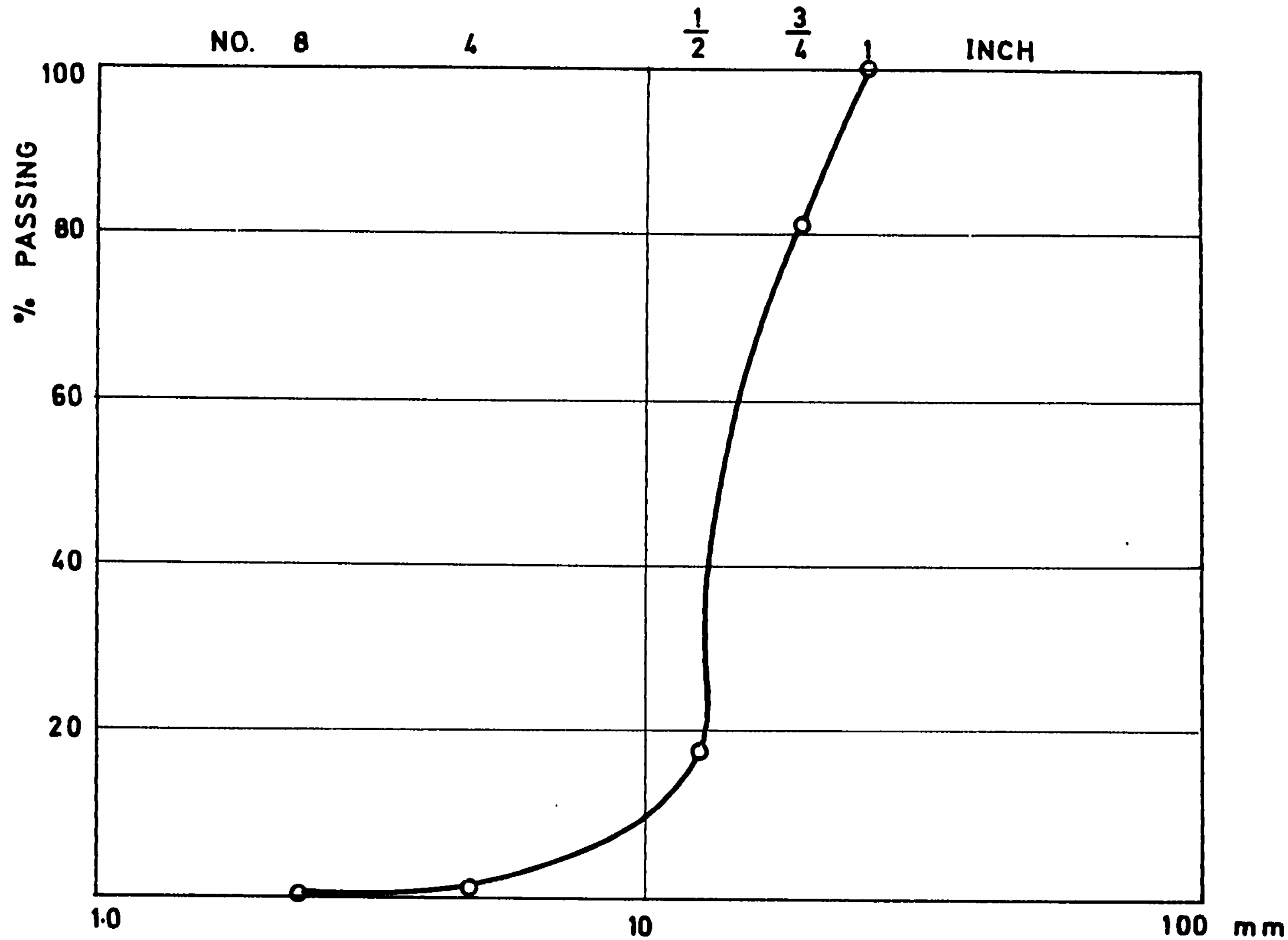

FIG. 16 QUARRY NO. 12 GRADING CURVE

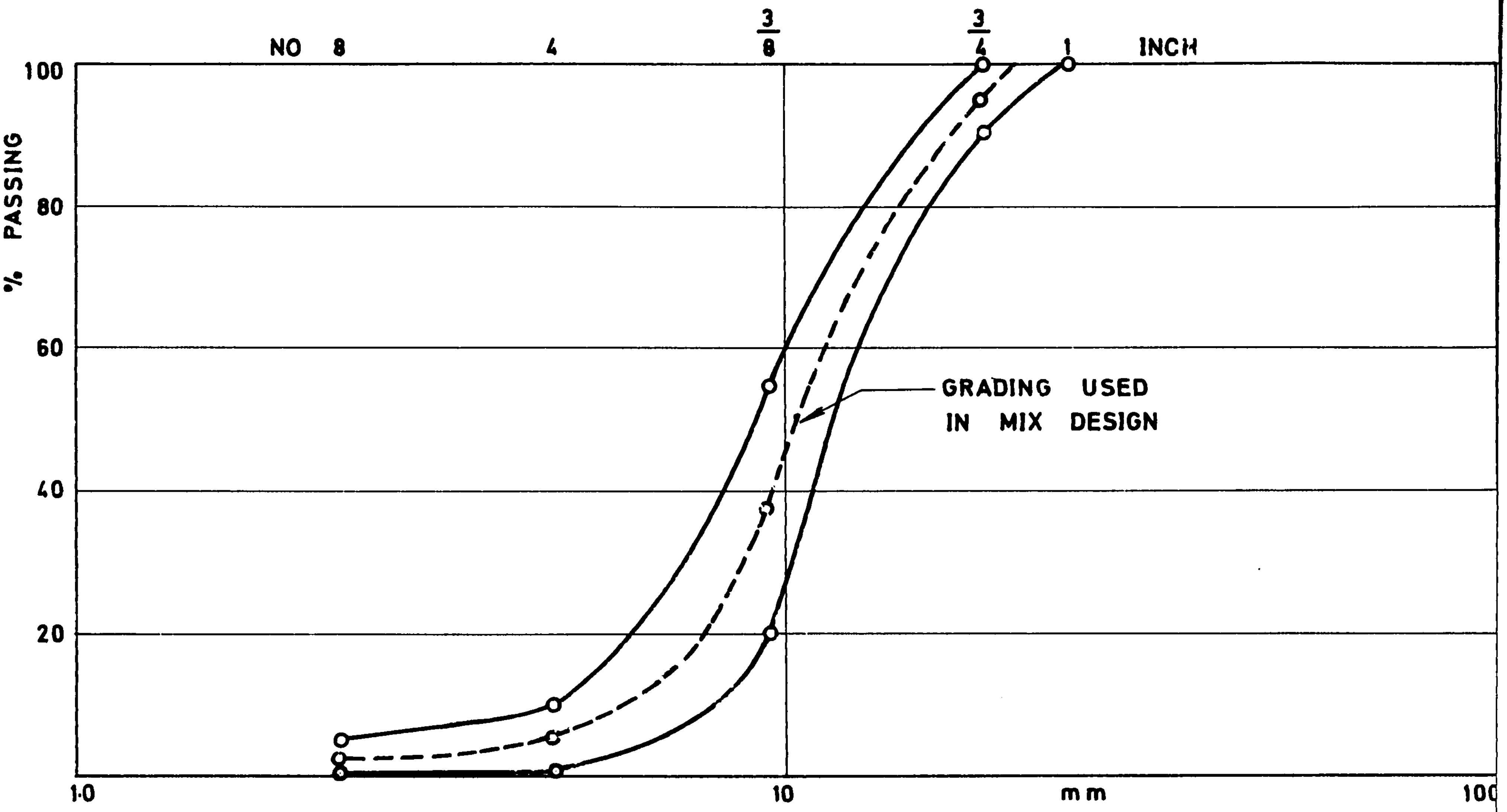

FIG.17 ASTM C 33 GRADING LIMITS FOR $\frac{3}{4}''$ (19mm)

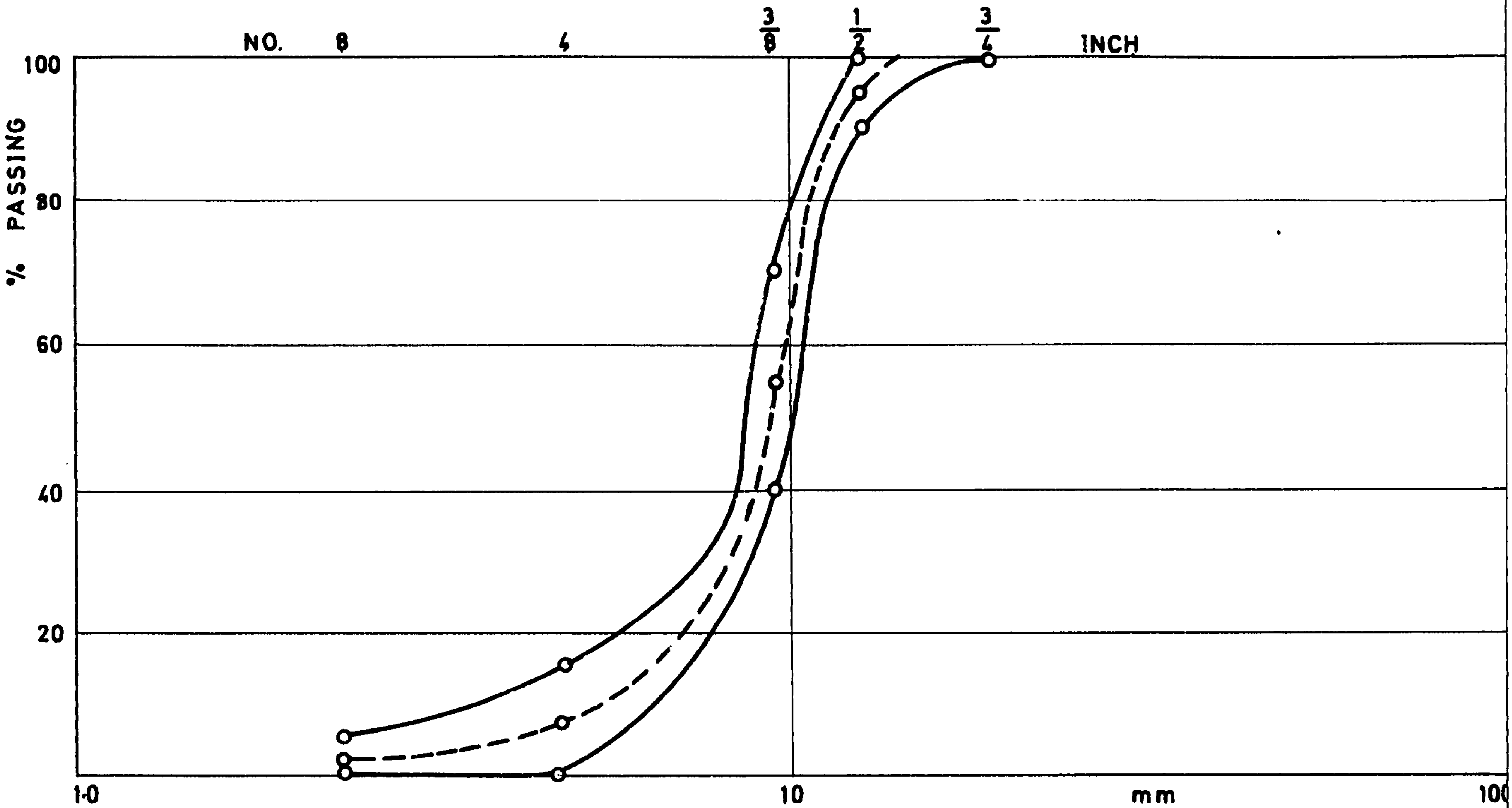

FIG. 18 ASTM C 33 GRADING LIMITS FOR $\frac{1''}{2}$ (12·5 mm)

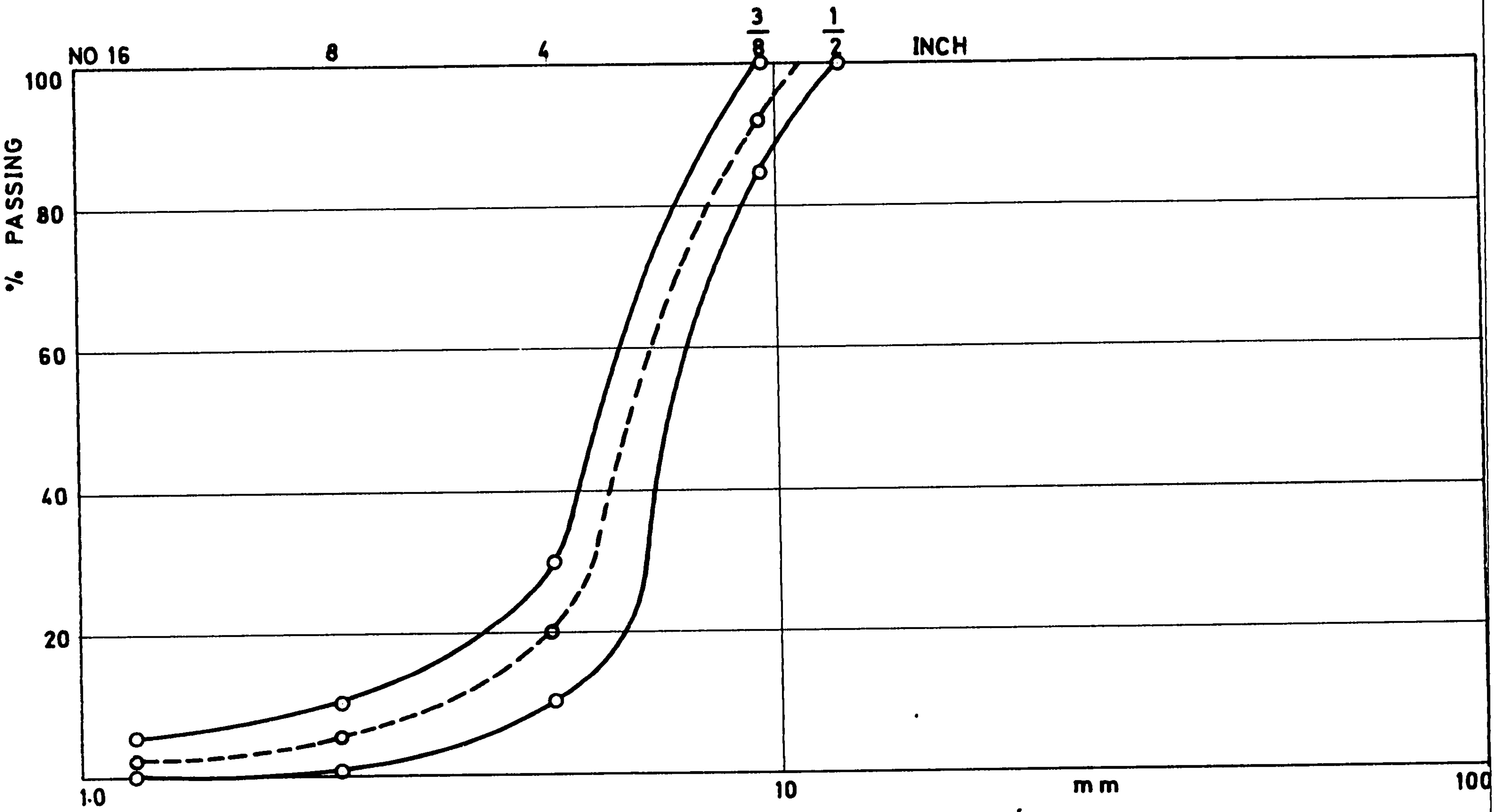

FIG. 19 ASTM C 33 GRADING LIMITS FOR 3/8" (9.5mm)

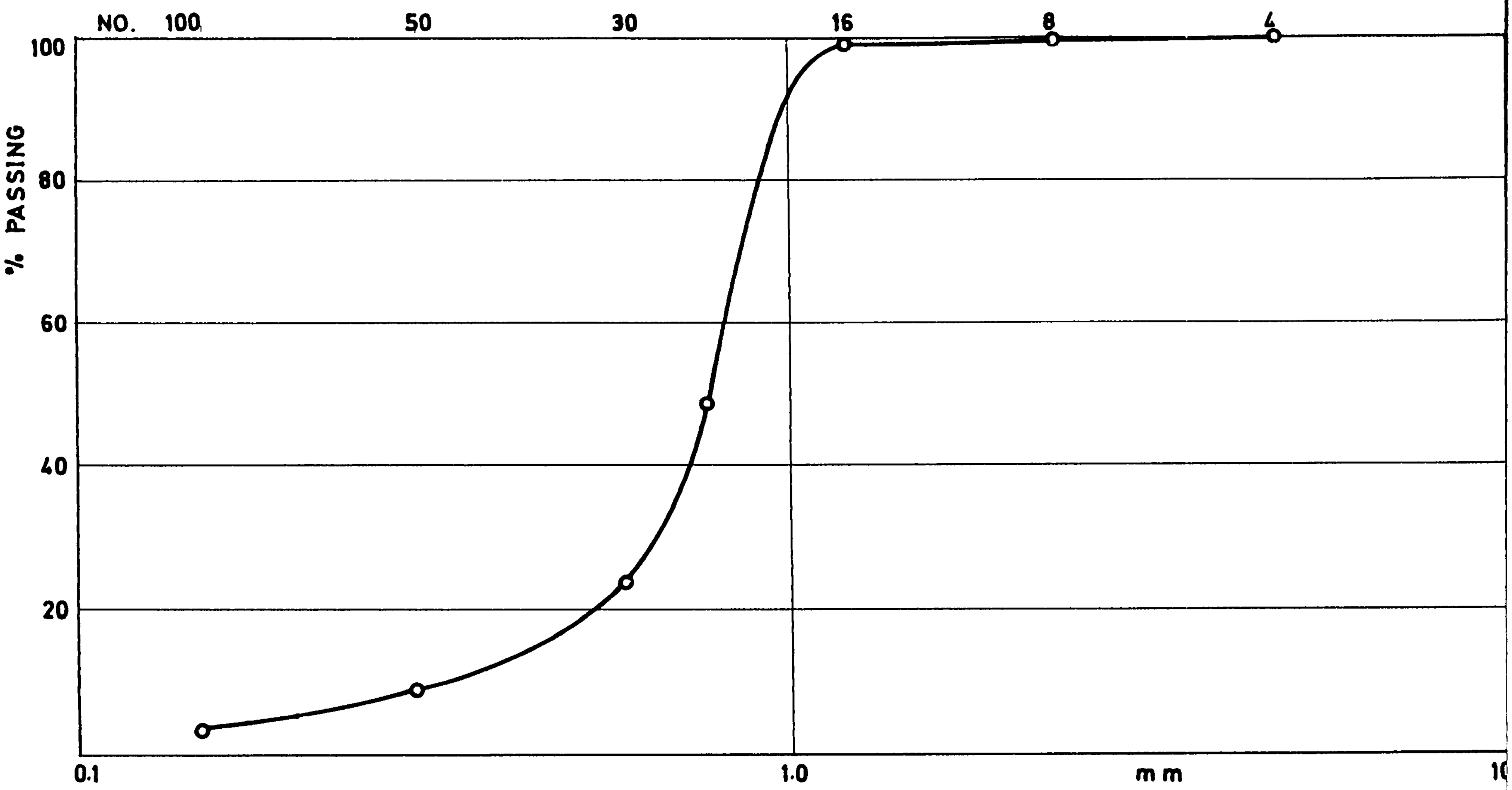

FIG. 20 HALF-MOON SAND GRADATION CURVE

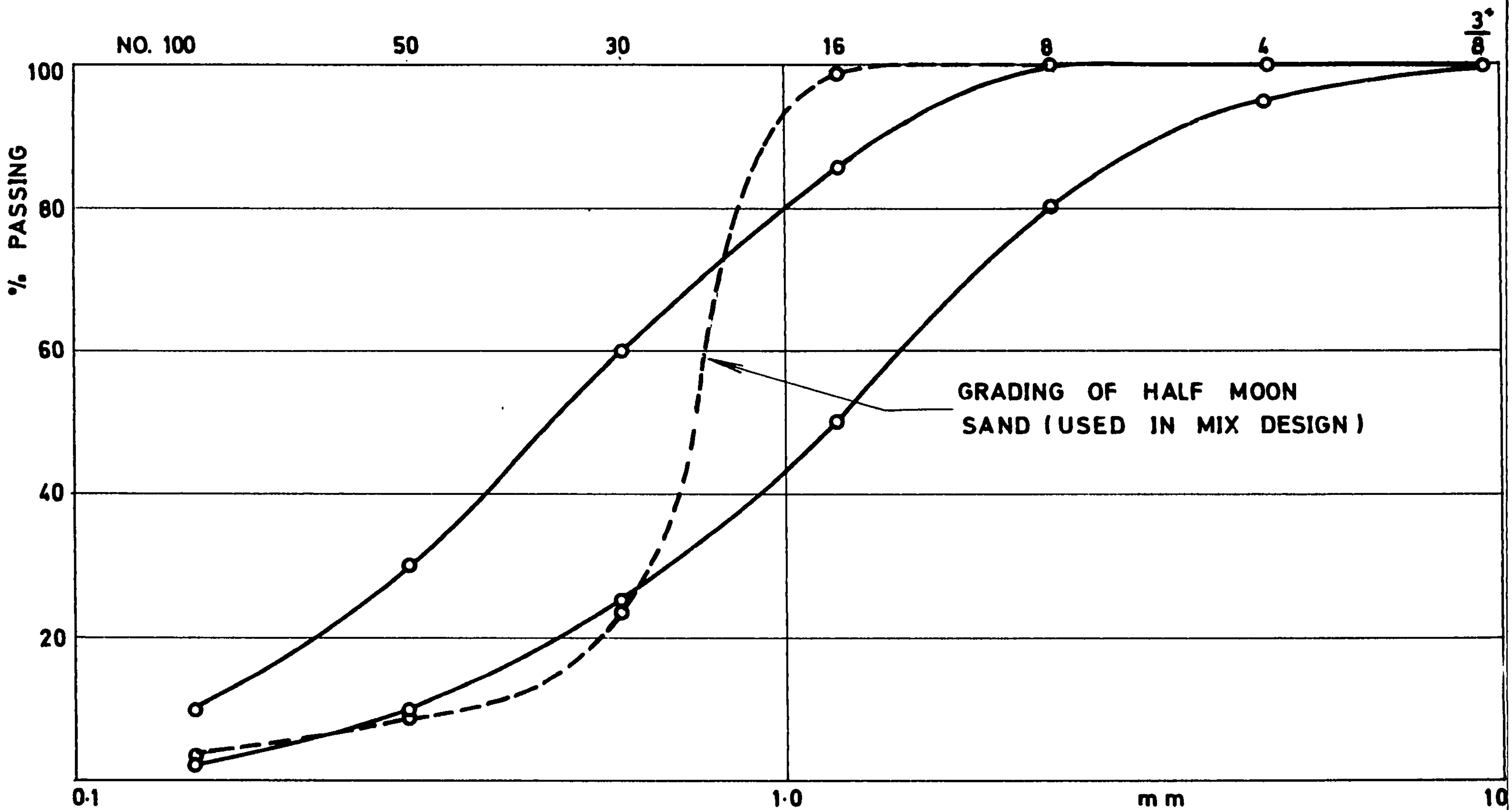

FIG. 21 ASTM C 33 GRADING LIMITS FOR FINE AGGREGATE

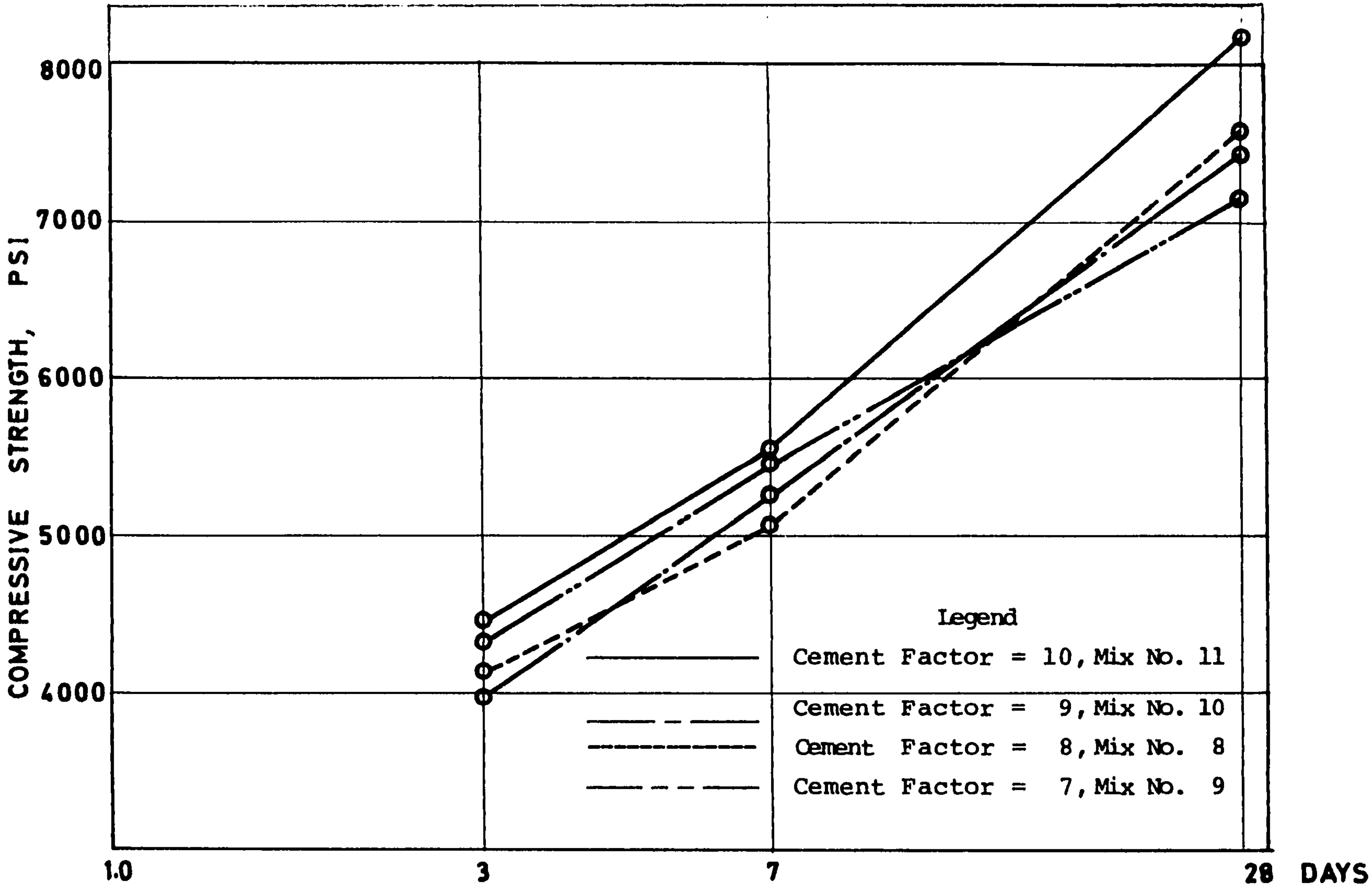

FIG.22 EFFECT OF CEMENT CONTENT ON CONCRETE COMPRESSIVE STRENGTH.

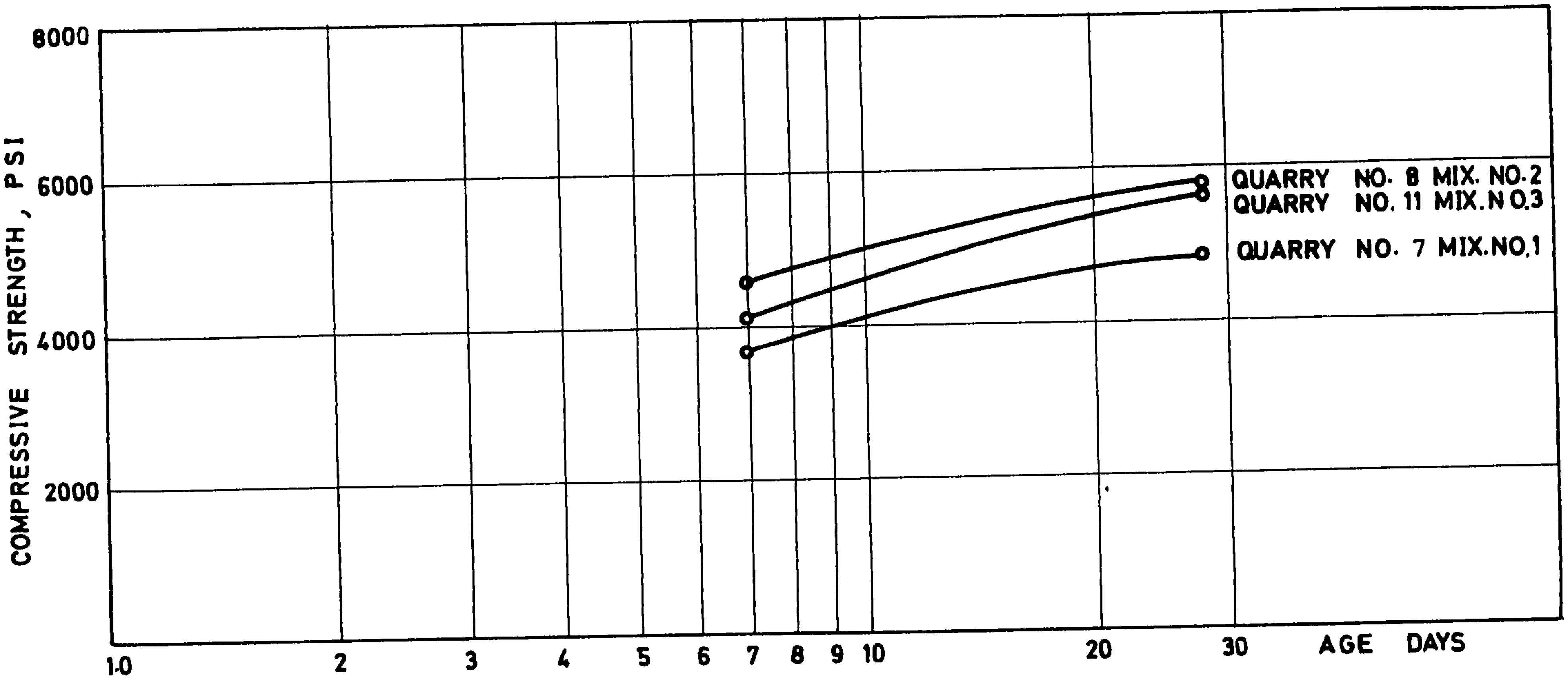

FIG. 23 COMPRESSIVE STRENGTH OF CONCRETE FOR VARIOUS QUARIES

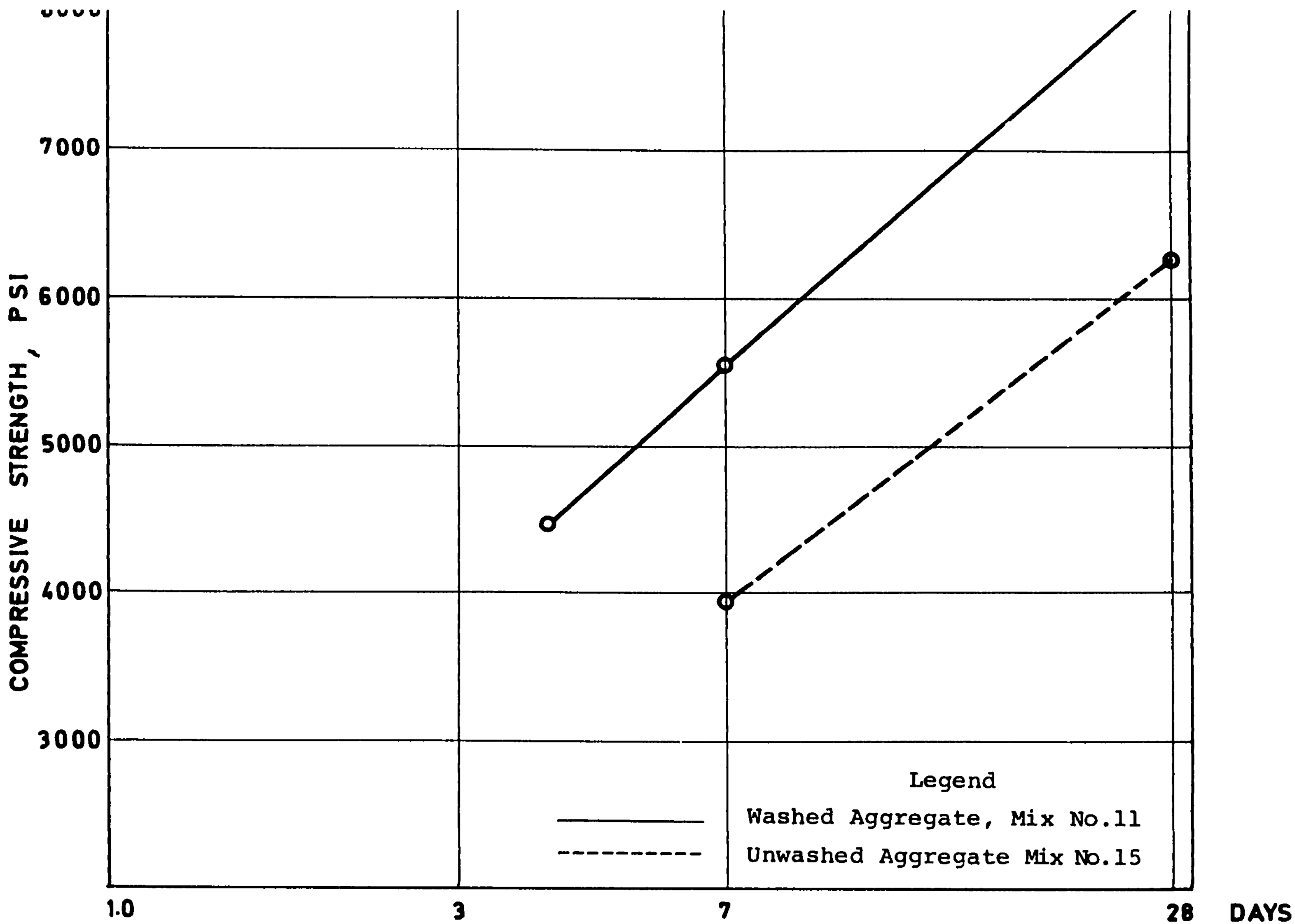

FIG. 24 EFFECT OF AGGREGATE WASHING ON COMPRESSIVE STRENGTH.

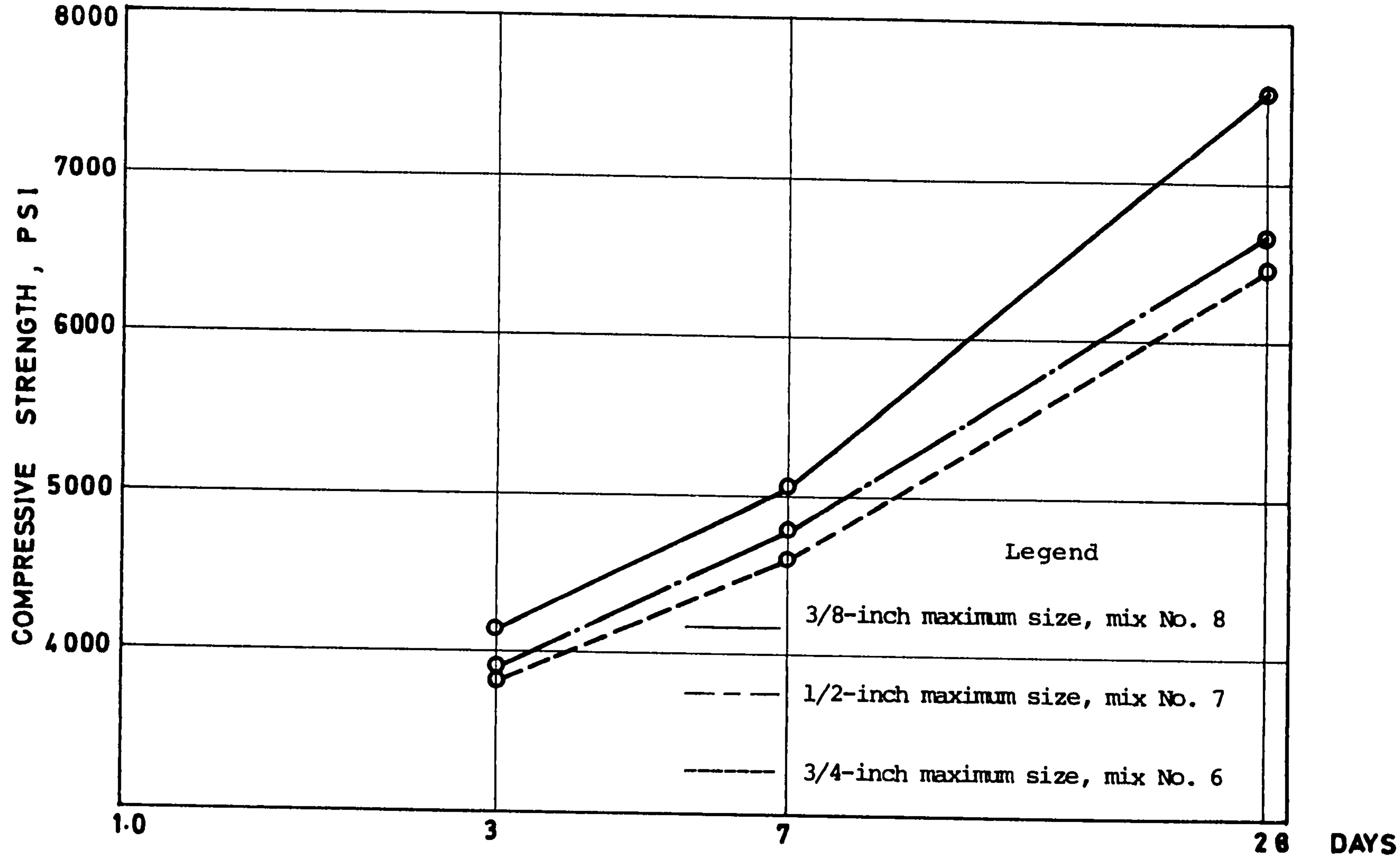

FIG. 25 EFFECT OF MAXIMUM AGGREGATE SIZE ON CONCRETE COMPRESSIVE STRENGTH

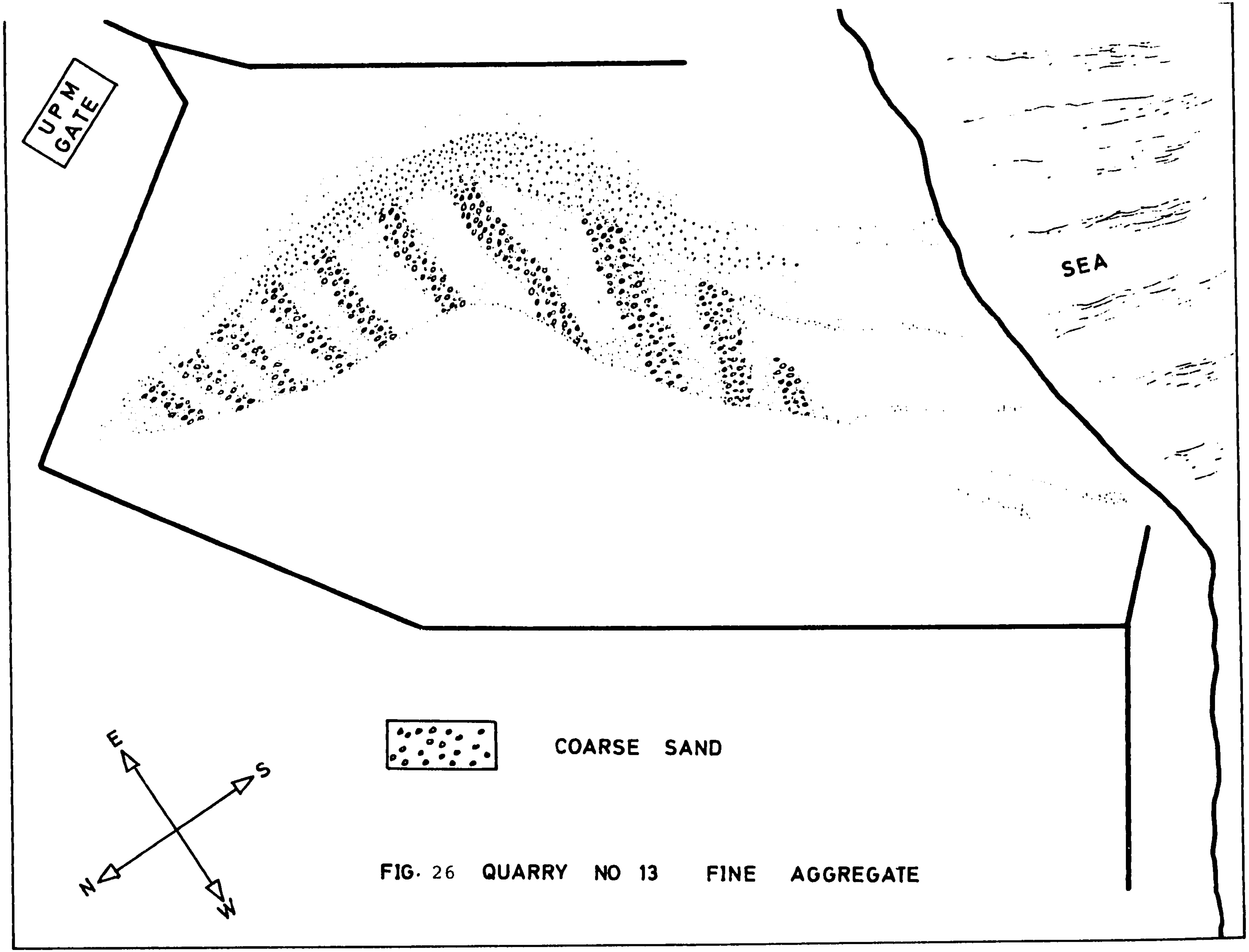

FIG. 26 QUARRY NO 13 FINE AGGREGATE

Mix No	Quarry Selection		
1			
2			
3			
Quarry #	7	8	11

Mix No	Choice of Maximum Aggregate Size		
6			
7			
8			
Size, In	3/4	1/2	3/8

Mix No	Study of Cement Factor Effect			
8				
9				
10,11				
C. F.	7	8	9	10

Mix No	Optimum Sand/ Aggregate Ratio		
11			
12			
13			
Ratios	.3	.35	.4

Mix No	Effect of Washing
11	
15	

Mix No	Effect of The Use of Admixtures		
16			
17			
18			
Type	300 N	748 ME	716

Figure-27

Mix Design Flow Chart

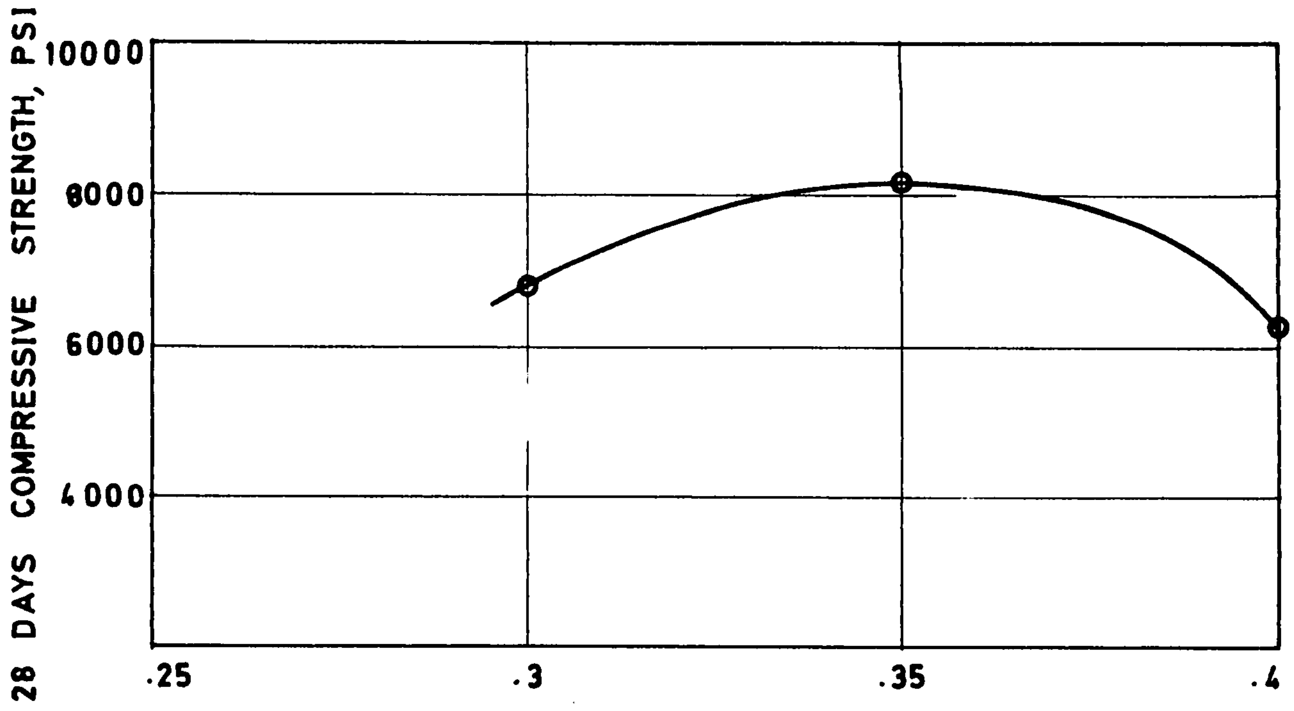

FIG. 28 $\frac{\text{SAND}}{\text{AGGREGATE}}$ RATIO

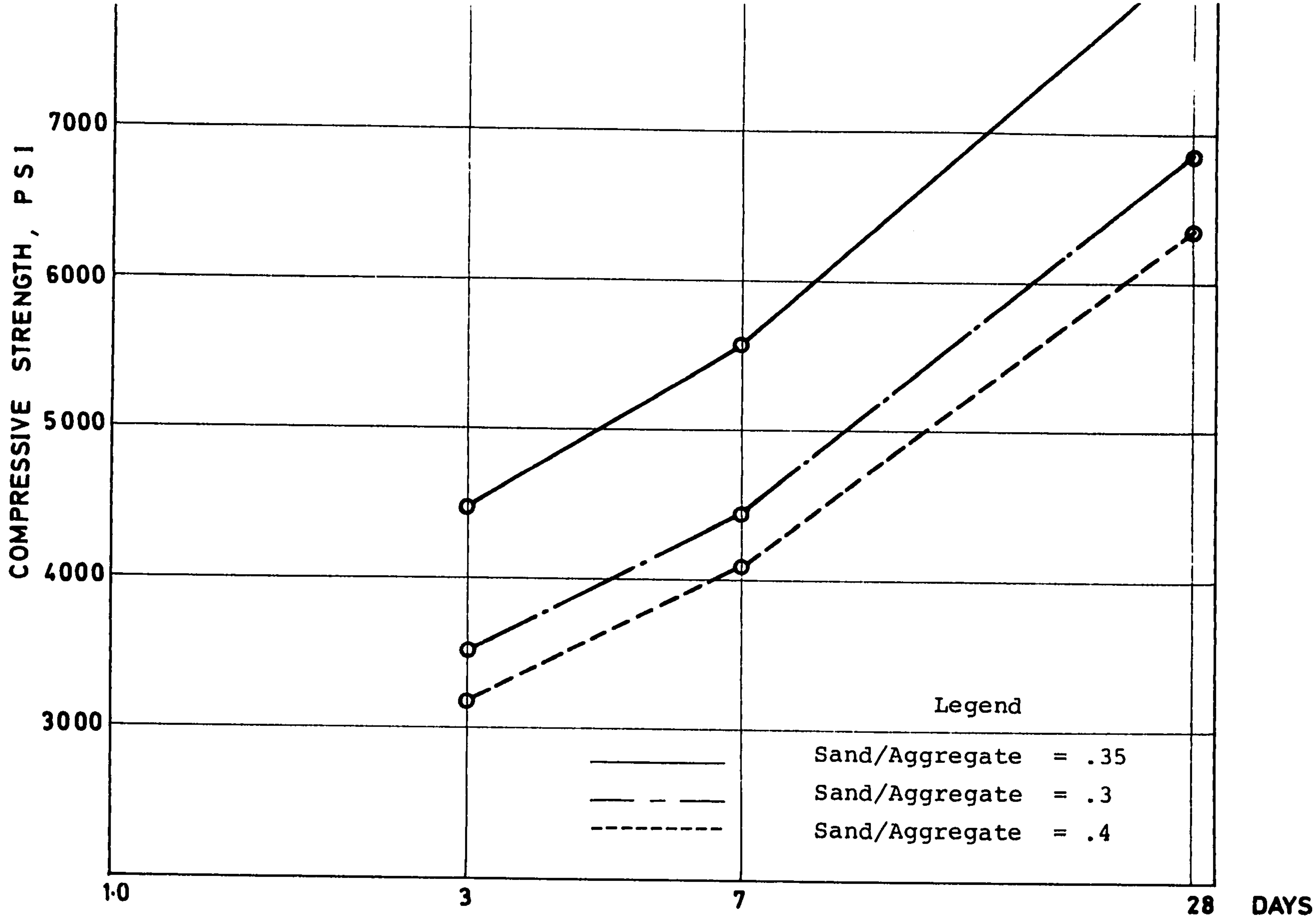

FIG.29 EFFECT OF SAND / AGGREGATE RATIO ON CONCRETE COMPRESSIVE STRENGTH

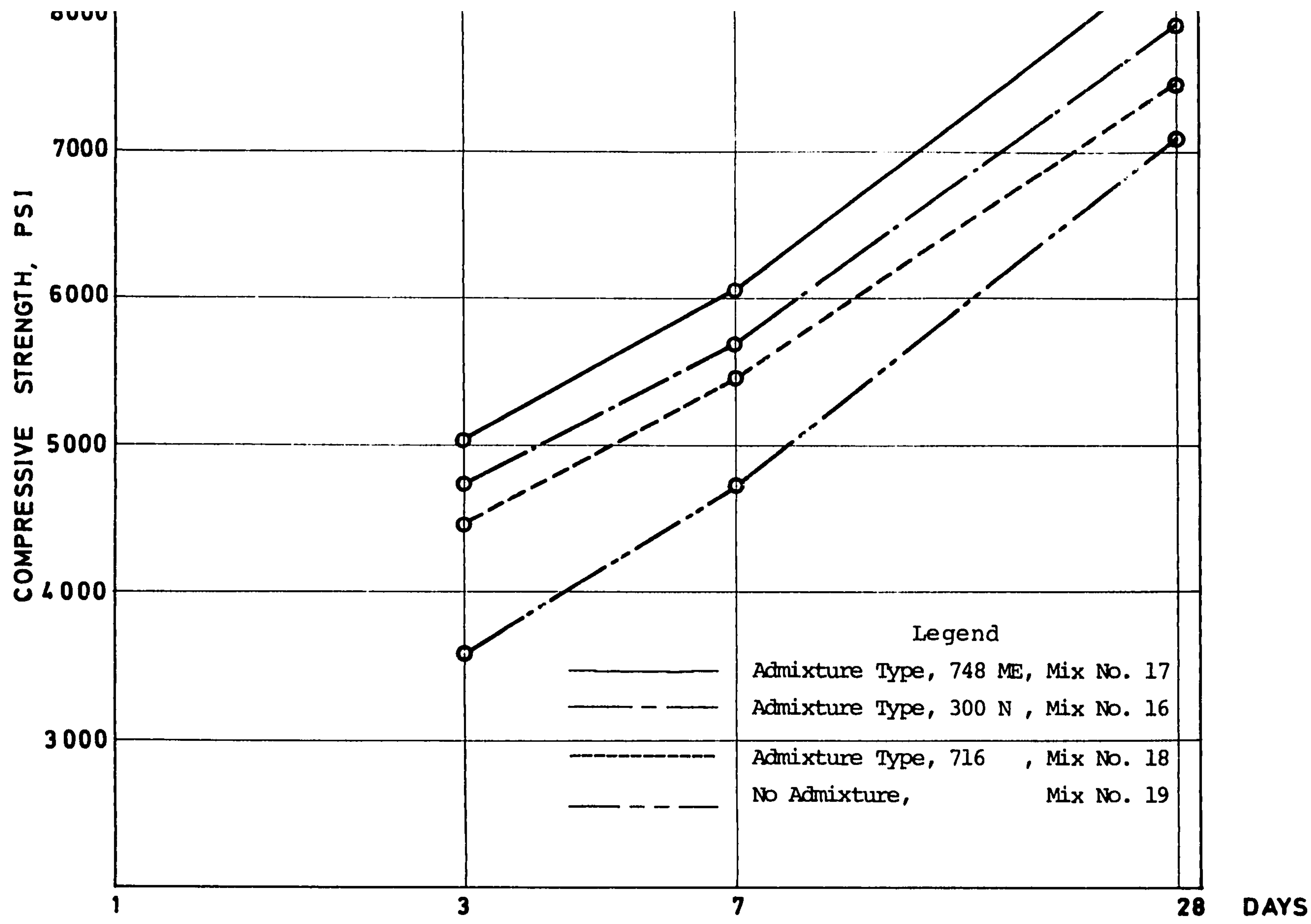

FIG. 30 EFFECT OF ADMIXTURE ON CONCRETE COMPRESSIVE STRENGTH.

APPENDIX A

Kingdon of Saudi Arabia
Ministry of Petroleum and Minerals Resources
Office of the Director of Administration,
Dammam

List of Crusher Owners Licensee By the Ministry of Petroleum

Crusher Owner	Location	Quarry No.
Abdulla Bin Huraib	Dhahran	7
Nassir Hazza and Brothers	Dhahran	
Heet Establishment	Dhahran	6
Yousef Al-Gossib	Dhahran	
Muhammad Alaide	Dhahran	
Rashed and Omran	Dhahran	
Tradco	Dhahran	12
Al Ailian	Dhahran	5
Prince Turkey and Swaikt	Safina Road	11
Hundiy	Safina Road	4
Amer Al-Dossary	Safina Road	
Al-Ghdair	Hofuf	2
Rashed and Omran	Hofuf	
Al-Arfj	Hofuf	8
Jabal Dhahran	Dhahran	3
UNLICENSED QUARRIES		
Muta'b Almazyad & Garib Muhammad	Dhahran	1
Al-Nahass	Al-Agrabia	9
Shemmeri and Otaibi	Al-Agrabia	10

APPENDIX B

AGGREGATE QUARRY QUESTIONNAIRE

Page 202-213

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 1 Date 15/2/ 1978

Quarry Name Motaib & Ghraib Crusher Location Dhahran Area

1. When did you start? 1977

2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [ ] Shoveling [x]

3. How deep do you go to get the rocks? 1 meter

4. What are the sizes of aggregate you are producing?

   2" [ ] 1½" [ ] 1" [ ] 3/4" [x] 5/8" [ ] ½" [x]

   3/8" [x] 1/4" [ ] 3/16" [ ] 1/8" [ ] No 10 [ ] Powder [x]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.			30		30	28	

8. How many cubic yards do you produce daily? 350 cu. yds.

9. Do you produce for own use or for selling?
   own use [ ] selling [x] both [ ]

10. For what purposes the aggregates are mainly used?
    Highway construction [x] Building construction [x]

11. Do you sell to ready mix plants? yes [ ] No [x]

12. What are the main problems you are facing?
    Quarry license [ ] Technical & spare parts [x]
    Prices drop and low market [ ]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 2 Date 20/1/1978

Quarry Name Al-Ghdair Crusher Location Hofuf Area

1. When did you start? 1975

2. Do you use Blasting or Shoveling to get the rocks?

   Blasting and Shoveling [x] Shoveling [ ]

3. How deep do you go to get the rocks? 10 meters

4. What are the sizes of aggregate you are producing?

2" [ ]	$1\frac{1}{2}$" [ ]	1" [x]	$\frac{3}{4}$" [x]	$\frac{5}{8}$" [ ]	$\frac{1}{2}$" [x]
$\frac{3}{8}$" [x]	$\frac{1}{4}$" [ ]	$\frac{3}{16}$" [ ]	$\frac{1}{8}$" [ ]	No. 10 [ ]	Powder [x]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.			45		45	45	

8. How many cubic yards do you produce daily? 400 cu. yds.

9. Do you produce for own use or for selling?

   own use [ ] selling [ ] both [x]

10. For what purposes the aggregates are mainly used?

    Highway construction [x] Building construction [x]

11. Do you sell to ready mix plants? yes [ ] No [x]

12. What are the main problems you are facing?

    Quarry license [ ] Technical & spare parts [ ]

    Prices drop and low market [x]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 3 Date 10/2/1978

Quarry Name Jabal Dhahran Crusher Location Dhahran Area

1. When did you start? 1977

2. Do you use Blasting or Shoveling to get the rocks?

   Blasting and Shoveling [x] Shoveling [ ]

3. How deep do you go to get the rocks? 3 meters

4. What are the sizes of aggregate you are producing?

   2" [x] 1½" [ ] 1" [x] 3/4" [x] 5/8" [ ] ½" [x]

   3/8" [x] 1/4" [ ] 3/16" [ ] 1/8" [ ] No 10 [ ] Powder [x]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.	30		30		30	30	

8. How many cubic yards do you produce daily? 1000 cu. yds.

9. Do you produce for own use or for selling?

   own use [ ] selling [x] both [ ]

10. For what purposes the aggregates are mainly used?

    Highway construction [x] Building construction [x]

11. Do you sell to ready mix plants? yes [x] No [ ]

12. What are the main problems you are facing?

    Quarry license [ ] Technical & spare parts [ ]

    Prices drop and low market [ ]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 4 Date 2/1/1978

Quarry Name Hundy Crusher Location Safina Area

1. When did you start? 1975

2. Do you use Blasting or Shoveling to get the rocks?

   Blasting and Shoveling [x] Shoveling [ ]

3. How deep do you go to get the rocks? 4.5 meters

4. What are the sizes of aggregate you are producing?

2" [ ]	1½" [ ]	1" [x]	3/4" [x]	5/8" [ ]	½" [x]
3/8" [ ]	1/4" [ ]	3/16" [ ]	1/8" [ ]	No 10 [ ]	Powder [ ]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.							

8. How many cubic yards do you produce daily? 200 cu. yds.

9. Do you produce for own use or for selling?

   own use [x] selling [ ] both [ ]

10. For what purposes the aggregates are mainly used?

    Highway construction [x] Building construction [x]

11. Do you sell to ready mix plants? yes [ ] No [ ]

12. What are the main problems you are facing?

    Quarry license [ ] Technical & spare parts [ ]

    Prices drop and low market [ ]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 5 Date 25/1/1978

Quarry Name Al-Alyyan Crusher Location Dhahran Area

1. When did you start? 1976

2. Do you use Blasting or Shoveling to get the rocks?

   Blasting and Shoveling ☐ Shoveling ☒

3. How deep do you go to get the rocks? 1 meter

4. What are the sizes of aggregate you are producing?

   2" ☒ 1½" ☐ 1" ☐ $\frac{3}{4}$" ☒ $\frac{5}{8}$" ☐ ½" ☒

   $\frac{3}{8}$" ☒ $\frac{1}{4}$" ☐ $\frac{3}{16}$" ☐ $\frac{1}{8}$" ☐ No 10 ☐ Powder ☐

5. Do you grade the aggregates? yes ☐ No. ☒

6. Do you wash the aggregates? yes ☐ No. ☒

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.	30		32		32	32	

8. How many cubic yards do you produce daily? 400 cu. yds.

9. Do you produce for own use or for selling?

   own use ☐ selling ☒ both ☐

10. For what purposes the aggregates are mainly used?

    Highway construction ☒ Building construction ☒

11. Do you sell to ready mix plants? yes ☐ No ☒

12. What are the main problems you are facing?

    Quarry license ☐ Technical & spare parts ☒

    Prices drop and low market ☐

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 6 | Date 12/12/1978

Quarry Name Heet Crusher | Location Dhahran Area

1. When did you start? 1977
2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [ ] Shoveling [x]
3. How deep do you go to get the rocks? 1 meter
4. What are the sizes of aggregate you are producing?

2" [ ]	$1\frac{1}{2}$" [x]	1" [ ]	$\frac{3}{4}$" [x]	$\frac{5}{8}$" [ ]	$\frac{1}{2}$" [x]
$\frac{3}{8}$" [x]	$\frac{1}{4}$" [x]	$\frac{3}{16}$" [ ]	$\frac{1}{8}$" [ ]	No. 10 [ ]	Powder [ ]

5. Do you grade the aggregates? yes [x] No. [ ]
6. Do you wash the aggregates? yes [ ] No. [x]
7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.		29	32		32	30	

8. How many cubic yards do you produce daily? 500 cu. yds.
9. Do you produce for own use or for selling?
   own use [ ] selling [x] both [ ]
10. For what purposes the aggregates are mainly used?
    Highway construction [x] Building construction [x]
11. Do you sell to ready mix plants? yes [ ] No [x]
12. What are the main problems you are facing?
    Quarry license [ ] Technical & spare parts [ ]
    Prices drop and low market [x]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 7 Date 5/11/1978

Quarry Name Ibn-Huraib Crusher Location Dhahran Area

1. When did you start? 1976

2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [x] Shoveling [ ]

3. How deep do you go to get the rocks? 6 meters

4. What are the sizes of aggregate you are producing?

2" [ ]	$1\frac{1}{2}$" [ ]	1" [x]	$\frac{3}{4}$" [x]	$\frac{5}{8}$" [x]	$\frac{1}{2}$" [x]
$\frac{3}{8}$" [x]	$\frac{1}{4}$" [ ]	$\frac{3}{16}$" [ ]	$\frac{1}{8}$" [ ]	No. 10 [ ]	Powder [x]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.			35	40	40	40	

8. How many cubic yards do you produce daily? 2000 cu. yds.

9. Do you produce for own use or for selling?

   own use [ ] selling [x] both [ ]

10. For what purposes the aggregates are mainly used?

    Highway construction [x] Building construction [x]

11. Do you sell to ready mix plants? yes [x] No [ ]

12. What are the main problems you are facing?

    Quarry license [ ] Technical & spare parts [ ]

    Prices drop and low market [x]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 8 Date 15/1/1978

Quarry Name Al-Arfj Crusher Location Hofuf Area

1. When did you start? 1976

2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [x] Shoveling [ ]

3. How deep do you go to get the rocks? 4 meters

4. What are the sizes of aggregate you are producing?

2" [ ]	$1\frac{1}{2}$" [ ]	1" [ ]	$\frac{3}{4}$" [x]	$\frac{5}{8}$" [ ]	$\frac{1}{2}$" [x]
$\frac{3}{8}$" [x]	$\frac{1}{4}$" [ ]	$\frac{3}{16}$" [x]	$\frac{1}{8}$" [ ]	No. 10 [ ]	Powder [x]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.			35		35	35	5

8. How many cubic yards do you produce daily? 400 cu. yds.

9. Do you produce for own use or for selling?
   own use [ ] selling [x] both [ ]

10. For what purposes the aggregates are mainly used?
    Highway construction [x] Building construction [x]

11. Do you sell to ready mix plants? yes [ ] No [ ]

12. What are the main problems you are facing?
    Quarry license [ ] Technical & spare parts [x]
    Prices drop and low market [x]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 9 Date 15/10/1978

Quarry Name Al-Nahass Crusher Location Al-Agrabia - Al-Khobar Area

1. When did you start? 1954
2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [x] Shoveling [ ]
3. How deep do you go to get the rocks? 10 meters
4. What are the sizes of aggregate you are producing?

   2" [ ] $1\frac{1}{2}$" [ ] 1" [x] $\frac{3}{4}$" [x] $\frac{5}{8}$" [ ] $\frac{1}{2}$" [x]

   $\frac{3}{8}$" [x] $\frac{1}{4}$" [ ] $\frac{3}{16}$" [ ] $\frac{1}{8}$" [ ] No. 10 [ ] Powder [x]
5. Do you grade the aggregates? yes [ ] No. [x]
6. Do you wash the aggregates? yes [ ] No. [x]
7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.		25	35		35	30	

8. How many cubic yards do you produce daily? 800 cu. yds.
9. Do you produce for own use or for selling?
   own use [ ] selling [x] both [ ]
10. For what purposes the aggregates are mainly used?
    Highway construction [ ] Building construction [x]
11. Do you sell to ready mix plants? yes [ ] No [x]
12. What are the main problems you are facing?
    Quarry license [x] Technical & spare parts [ ]
    Prices drop and low market [x]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 10 Date 20/10/1978

Quarry Name Shemere & Otaibi Crusher Location Al-Agrabia - Al-Khobar

1. When did you start? 1971

2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [x] Shoveling [ ]

3. How deep do you go to get the rocks? 3 meters

4. What are the sizes of aggregate you are producing?

2" [ ]	1½" [ ]	1" [ ]	$\frac{3}{4}$" [ ]	$\frac{5}{8}$" [ ]	½" [x]
$\frac{3}{8}$" [x]	$\frac{1}{4}$" [ ]	$\frac{3}{16}$" [ ]	$\frac{1}{8}$" [ ]	No 10 [ ]	Powder [x]

5. Do you grade the aggregates? yes [ ] No. [x]

6. Do you wash the aggregates? yes [ ] No. [x]

7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.					50	40	10

8. How many cubic yards do you produce daily? 250 cu. yds.

9. Do you produce for own use or for selling?
   own use [ ] selling [x] both [ ]

10. For what purposes the aggregates are mainly used?
    Highway construction [ ] Building construction [x]

11. Do you sell to ready mix plants? yes [ ] No [x]

12. What are the main problems you are facing?
    Quarry license [ ] Technical & spare parts [x]
    Prices drop and low market [ ]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 11 Date 3/1/1978

Quarry Name Prince Turkey & Swiakt Crusher Location Safina Area

1. When did you start? 1975
2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [ ] Shoveling [x]
3. How deep do you go to get the rocks? 1 meter
4. What are the sizes of aggregate you are producing?
   2" [ ] 1½" [ ] 1" [ ] 3/4" [x] 5/8" [ ] ½" [x]
   3/8" [x] 1/4" [ ] 3/16" [ ] 1/8" [ ] No. 10 [ ] Powder [ ]
5. Do you grade the aggregates? yes [ ] No. [x]
6. Do you wash the aggregates? yes [ ] No. [x]
7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.			50		50	55	

8. How many cubic yards do you produce daily? 400 cu. yds.
9. Do you produce for own use or for selling?
   own use [ ] selling [ ] both [x]
10. For what purposes the aggregates are mainly used?
    Highway construction [x] Building construction [x]
11. Do you sell to ready mix plants? yes [ ] No [x]
12. What are the main problems you are facing?
    Quarry license [ ] Technical & spare parts [ ]
    Prices drop and low market [ ]

AGGREGATE QUARRY QUESTIONNAIRE

Quarry No. 12 Date 20/11/1978

Quarry Name Tradco Crusher Location Dhahran Area

1. When did you start? 1975
2. Do you use Blasting or Shoveling to get the rocks?
   Blasting and Shoveling [x] Shoveling [ ]
3. How deep do you go to get the rocks? 6 meters
4. What are the sizes of aggregate you are producing?

2" x	1½" x	1" x	3/4" x	5/8"	½" x
3/8" x	1/4"	3/16"	1/8" x	No 10 x	Powder

5. Do you grade the aggregates? yes [x] No. [ ]
6. Do you wash the aggregates? yes [ ] No. [x]
7. What is the selling price per cubic yard?

Size inches	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	Powder
price S.R.	30	30	37		37	37	

8. How many cubic yards do you produce daily? 1800 cu. yds.
9. Do you produce for own use or for selling?
   own use [ ] selling [ ] both [ ]
10. For what purposes the aggregates are mainly used?
    Highway construction [x] Building construction [x]
11. Do you sell to ready mix plants? yes [ ] No [x]
12. What are the main problems you are facing?
    Quarry license [ ] Technical & spare parts [ ]
    Prices drop and low market [x]

APPENDIX : C

SAUDI CEMENT COMPANY
FACTORY

CEMENT TESTING CERTIFICATE:

According to ASTM - C - 150/7 Type V

CHEMICAL ANALYSIS			
		Results Obtained	Required by Specification
Silica	SiO_2	23.95	
Insoluble residue		0.21	Max. 0.75%
Aluminium Oxide	Al_2O_3	2.59	
Iron Oxide	Fe_2O_3	4.02	
Lime	Ca O	64.12	
Magnesium Oxide	Mg O	2.33	Max. 5.0 %
Sulphur Trioxide	$S\ O_3$	1.55	Max. 2.3 %
Loss On Ignition		0.85	Max. 3.0 %
Alkalies and Loss		0.38	
3 Ca O. Al_2O_3	C_3 A	0.06	Max. 6.0 %
4 Ca O. Al_2O_3 Fe_2O_3	C_4AE	12.4	
Ca AF + 2 C A		12.52	Max. 20.0 %

PHYSICAL TESTING			
Setting time:	Initial	120	Not less than 45 mins.
Vicat test:	Final	3 hrs.	Not more than 8 hours.
Fineness: Specific Surface (Blaine)		3300	Min. Average 2800 Cm^2/g
Le Chatelier Expansion Soundness:	Autoclave test: BS: 12/1958	1.0	Max. 10 mm
Compressive Strength lb./sq. in.			
1 day in moist air, 2 days in water		2265	Min. 1200 lb./sq. in.
1 day in moist air, 6 days in water		3090	Min. 2200 lb./sq. in.
1 day in moist air, 27 days in water		4150	Min. 3000 lb./sq. in.

Appendix: D

WATER-REDUCING ADMIXTURES

Trade Name	Manufacturer	Type	Dosage	Cost SR/210 liter
Pozzolity 300 N	Master Builders	Hydroxylated Polymers	195-275 ml/100kg cement	1000
Pozzolith 748 ME	Master Builders	Hydroxylated Polymers	200-325 ml/100kg cement	1200
Rheomac 716	Master Builder	Hydroxylated	2 $\pm$ .5 liters/ 100kg cement	950

Mixing Water Analysis

APPENDIX:E

The London Analytical and

Testing Laboratories Ltd.

CERTIFICATE OF ANALYSIS

Sample of water Ex-University of Petroleum & Minerals, Dhahran, Saudi Arabia.

Submitted by: Engineering Power and Development Co. Ltd.,

Received on : 24th February, 1977.

Sample (content in p.p.m)	Building 1
Sodium	210
Calcium	39.2
Magnesium	17.3
Chlorides as Cl	241
Sulphates as So4	233
Total Dissolved Solids	792.8
PH Value	7.28
Colour	Less than 5 Hazen Units
Taste	None
Appearance	Clear and Brilliant
Odour	None